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# Rheology Abstracts

## A Survey of World Literature

**Volume 3**

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**Contents**

A. Theoretical

B. Instruments and Techniques

C. Metals and other Solids

D. Polymers, Elastomers and Viscoelastic Materials

E. Pastes and Suspensions

F. Liquids

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# RHEOLOGY ABSTRACTS

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## Section A

## THEORETICAL

**1. Flow mechanism of thixotropic substances.** S. J. HAHN, T. REE, H. EYRING, *N.L.G.I. Spokesman*, 1959, **23**, 129–136. University of Utah, U.S.A. In a thixotropic system, there are two kinds of molecules, entangled and disentangled. Entangled molecules make a three-dimensional network, in which disentangled and solvent molecules are enclosed. The entangled molecule, whose flow behaviour is non-Newtonian, transforms to the disentangled molecule of Newtonian character as a result of stress. If the stress is relieved, the transformed molecule returns to its original state only after marked delay. Using this model, two flow equations are derived : One equation is applied to the " upcurve " which is obtained by measuring rates of shear with increasing stress, whereas the other is applied to the " downcurve ", the flow curve in the reverse direction of the upcurve. The authors' theory is applied to silicone oil, printing inks, shaving cream, heavy mineral oil, grease and mayonnaise with good agreement with experiment. Author

**2. Possibility of determining the shape, dimensions and mass of a rigid particle by measurement of viscosity only.** R. CERF, *J. Chim. Phys.*, 1958, **55**, 470–471. Univ. of Strasbourg, France. Normalized curves of viscosity vs. gradient and elongation of particles are given. Experimental data can be fitted to these plots to determine the properties of the particles. D.P.D.

**3. Thermodynamics and rheological problems.** H. ZIEGLER, *Ing.-Arch.*, **25**, 58–70. Rüschlikon, Zurich, Switzerland. Rheological systems (Newtonian, Hookean, Maxwell, Kelvin, and Prandtl-Reuss) of varying degrees of complexity are treated thermodynamically. D.P.D.

**4. On plane stress solution of an elastic, perfectly plastic wedge.** P. M. NAGHDI, *J. appl. Mech.*, 1958, **25**, 407–410. With the use of Tresca's yield function and its associated flow laws, the complete solution is obtained for an isotropic elastic, perfectly plastic wedge (with an included angle $\beta < \frac{\pi}{2}$) subjected to a uniform traction in the state of plane stress. Unlike its corresponding plane strain solution, the state of stress in a portion of the plastic domain of the wedge is at a corner of Tresca's yield hexagon where, in general, the normal to the yield surface is not defined uniquely. Author

**5. Effect of tensile plastic deformation on yield condition.** L. W. HU and J. F. BRATT, *J. appl. Mech.*, 1958, **25**, 411. A biaxial stress investigation on the effects of tensile plastic deformation on the yield condition is reported. It is concluded from the investigation that (i) the original yield surface is fairly in agreement with the von Mises yield condition ; (ii) the subsequent yield surface after prestressing in tension does not expand isotropically in all directions ; (iii) a yield corner is formed in the direction of the prestressing ; (iv) after prestressing in the axial direction by tension, the tensile yield stress in the tangential direction is reduced considerably from its value before prestressing.

**6. Stress-strain relations for a simple model of a granular medium.** H. DERESIEWICZ, *J. appl. Mech.*, 1958, **25**, 402–406. A granular assemblage is represented by a model consisting of like spheres in contact arranged in a simple cubic lattice. Based on consideration of local contact forces and concomitant deformations, incremental stress-strain relations are derived and subsequently integrated, for certain types of loading, to yield total stress–strain relations. The integration is carried out for both a loading and an unloading process. A criterion of failure for the model is set up and the theory applied to a regimen of loading which gives rise to a plane state of stress.

**7. The dynamics of thin sheets of fluid.—I. Water bells.** SIR GEOFFREY TAYLOR, F.R.S. (with an appendix by L. HOWARTH, F.R.S.), *Proc. Roy. Soc., A*, 1959, **255**, 289–295.

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**8. The dynamics of thin sheets of fluid.—II. Waves on fluid sheets.** SIR GEOFFREY TAYLOR, F.R.S., *Proc. Roy. Soc., A*, 1959, **253**, 296–312.

**9. The dynamics of thin sheets of fluid.—III. Disintegration of fluid sheets.** SIR GEOFFREY TAYLOR, F.R.S., *Proc. Roy. Soc., A*, 1959, **253**, 313–321.

**10. The elastic field outside an ellipsoidal inclusion.** J. D. ESHELBY, *Proc. Roy. Soc., A*, 1959, **252**, 561–569. Department of Metallurgy, University of Birmingham. The results of an earlier paper (*Proc. Roy. Soc., A*, **241**, 376) are extended. The elastic field outside an inclusion is treated in greater detail.

**11. Faults in a material that hardens when it yields.** SIR HAROLD JEFFREYS, F.R.S., *Proc. Roy. Soc., A*, 1959, **252**, 431–435. The problem of an elliptic inclusion in an elastic solid, with homogeneous stress at a large distance, is solved. The greatest stress differences are found to be at or near the ends of the flaw and to be determined mainly by the greatest principal stress. Author

**12. Elastic waves in anisotropic media.** V. T. BUCHWALD, *Proc. Roy. Soc., A*, 1959, **253**, 563–580. Department of Mathematics, The Manchester College of Science and Technology. The displacements due to a radiating point source in an infinite anisotropic elastic medium are found in terms of Fourier integrals. Author

**13. Relaxation theory of transport problems in condensed systems.** F. H. REE, T. REE, and H. EYRING, *Ind. Eng. Chem.*, 1958, **50**, 1036–1040. Department of Physics and Chemistry, University of Utah, Salt Lake City 12, Utah. The Ree–Eyring theory is used to derive the radial distribution of velocities in a circular tube. Eyring's early theory of diffusion is improved by including a factor representing the number of neighbouring molecules lying in the plane normal to the flow direction. R.H.B.

**14. Non-Newtonian flow in annuli.** A. G. FREDRICKSON and R. B. BIRD, *Ind. Eng. Chem.*, 1958, **50**, 347–352. Dept. of Chemical Engineering,

University of Wisconsin, Madison, Wis. Solves the equations of motion for the flow in an annulus of a Bingham material and a fluid in which the shear stress is some power of the shear rate. R.H.B.

**15. Generalised equation of state for gases and liquids.** J. O. HIRSCHFELDER, R. J. BUEHLER, H. A. MCGEE, and J. R. SUTTON, *Ind. Eng. Chem.*, 1958, **50**, 375–385. Naval Research Laboratory, University of Wisconsin, Madison, Wis. The equations are based on a modified principle of corresponding states and include the rare gases, hydrocarbons and the highly polar substances water and ammonia. The framework is believed to be adequate for practically all pure substances. R.H.B.

**16. Plane sliders of finite width.** D. F. HAYS, *A.S.L.E. Trans.*, 1958, **1**, 233–240. General Motors Corporation, P.O. Box No. 188, Detroit 2, Michigan. An analytical solution to the problem of lubrication of slider blocks of fixed wedge angle and finite width is presented. The method of solution is by the separation of variables which yields results conveniently shown in curve form illustrating the various slider properties. The analysis is not encumbered by the requirement of numerical or graphical methods of evaluation as in the case of Michell, and is similar in nature to the solutions of Muskat, Morgan and Meres wherein explicit analytical expressions are derived for the slider characteristics. The solutions appear in the form of convergent series. Author

**17. The viscosity wedge.** A. CAMERON, *A.S.L.E. Trans.*, 1958, 248–253. Imperial College, London. In a previous paper (1951) it was shown that a viscosity gradient across an oil film allowed a hydrodynamic load to be carried between contra-rotating discs. If there is a temperature (and viscosity) gradient, not only through the oil film but also in the direction of motion, a considerable load can be borne. The equations are set up and solved numerically giving co-efficient for oil film thickness and friction. The oil film thickness is comparable (three-quarters) to that carried by Michell pads. The computed results are applied to the parallel surface thrust bearing described by Fogg in 1946 and shown to give tolerable agreement with the experimental findings. Author

**18. Analysis of composite reinforced concrete structures.** M. BIENIEK, *Arch. Inzy. Ladowej, Warsz.*, 1959, **4**, No. 4, 411. Warsaw. [Polish]

**19. Certain properties of mechanical models of structures.** J. SKOWRONSKI and S. ZIEMBA, *Arch. Mech. Stosowanej*, 1959, **11**, No. 2, 193. A mathematical study is made of the behaviour of a material represented by a network of non-linear visco-elastic bodies of the Kelvin type. P.F.

**20. Studies in photoplasticity.** M. M. FROCHT and R. A. THOMSON, *Arch. Mech. Stosowanej*, 1959, **11**, No. 2, 157. Warsaw. The purpose of the paper is to show that the photoelastic method can be extended to the determination of stress distributions in models which are in the elastoplastic state. P.F.

**21. Thermal stresses due to the action of heat sources in a viscoelastic space.** W. NOWACKI, *Arch. Mech. Stosowanej.*, 1959, **11**, No. 1, 111. Warsaw.

**22. On a conception of basic solutions for orthotropic elastic and anelastic bodies.** S. KALISKI, *Arch. Mech. Stosowanej*, 1959, **11**, No. 1, 45. Warsaw. The object of the paper is a tentative achievement of a method of constructing exact basic solutions, and solving Cauchy's problem for anisotropic elastic and anelastic bodies with the number of elastic constants and relaxation functions greater than for transversally isotropic bodies. P.F.

**23. Forced vibration of a system of one degree of freedom due to periodic forces, with damping characterised by strong non-linearity.** Z. OSINSKI, *Arch. Mech. Stosowanej*, 1959, **11**, No. 1, 33. Warsaw.

**24. An iteration method for the solution of finite deformation problems in elasticity.** W. R. SEUGLING, *Arch. Mech. Stosowanej*, 1959, **11**, No. 1, 3. Warsaw.

**25. J. Cauchy's problem for a transversally isotropic elastic body.** S. KALISKI and J. KURLANDZKI, *Arch. Mech. Stosowanej*, 1958, **10**, No. 6, 825. Warsaw. The initial value problem is solved for a transversally isotropic body, mass forces being taken into account. P.F.

**26. The influence of non-linear characteristics of internal friction damping on forced vibrations.** Z. OSINSKI, *Rozpr. Inzyn.*, 1959, **7**, No. 1, 25. Warsaw. [Polish]

**27. Graphical determination of the distribution of stress in sheet strips subjected to plastic bending.** Z. MARCINIAK, *Rozpr. Inzyn.*, 1958, **6**, No. 4, 537. Warsaw. [Polish]

**28. Stress waves and fracture surfaces.** E. H. ANDREWS, *J. Appl. Phys.*, 1959, **30**, 740. The British Rubber Producers' Research Association, Welwyn Garden City, Hertfordshire, England. Surface markings observed in the brittle fracture of certain frozen rubbers display striking wave-like characteristics. They have been identified as "Wallner" lines, caused by the interaction of the fracture front with stress waves emanating from the region of the fracture front itself. These oscillations are possibly caused by the supply of excess energy to the fracture tip. A value of approximately 1 : 2 is obtained for the ratio of fracture velocity to wave velocity. Author

**29. Theory of creep limited by self-diffusion.** R. W. CHRISTY, *J. Appl. Phys.*, 1959, **30**, 760. Dartmouth College, Hanover, New Hampshire. A theory of steady-state creep at high temperature and stress is based on the climb of dislocations limited by the diffusion of vacancies from them. The creep rate is found to be approximately $(MnL^3)D^n\exp-(W+E+U-\Delta W)/kT$, where M is the number of dislocation sources per unit volume, n is the number of dislocations of length L per unit area, and $D_0\exp(-W/kT)$ is the coefficient of self-diffusion. The number of



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jogs in the dislocations is determined by U, and E is an activation energy for formation of vacancies, due to relaxation of the lattice. The reduction in vacancy formation energy near a dislocation $\Delta W$ is estimated from the interaction energy of the climbing dislocations. A comparison of experimental data for Zn and AgBr suggests that E is a significant contribution to the activation energy for ionic crystals but no much for metals. The predicted increase in vacancy concentration during creep is too small to give observable effects. It is concluded that any observed enhancement of diffusivity during creep is due to increased mobility of defects. Author

**30. On the foundations of the theory of elasticity of plane incompressible non-homogeneous bodies.** J. GOLECKI, *Arch. Mech. Stosowanej*, 1959, **11**, 383–399. Warsaw.

**31. Stress waves in a homogeneous elastic-visco-plastic medium.** P. PERZYNA, *Arch. Mech. Stosowanej*, 1959, **11**, 441–474. Warsaw.

**32. Sedimentation and effective viscosity.** G. J. KYNCH, *Nature, Lond.*, 1959, **184**, 1311. Dept. of Mathematics, Manchester College of Science and Technology, Manchester 1. A set of equations has been obtained which relates the sedimentation velocity of particles falling through a liquid to the effective viscosity of a suspension of similar particles having the same density as the fluid. From the analysis it should be possible to estimate the pressure gradient in the fluid due to the falling particles. W.G.C.

**33. Sedimentation rates, fluidisation and flow through porous media.** C. C. HARRIS, *Nature, Lond.*, 1959, **184**, 716. Dept. of Mining, The University, Leeds, 2. The equations derived in a previous paper on the correlation of sedimentation rates by use of dimensionless groups (*Ibid.*, 1959, **183**, 530–531, *Rheology Abstracts*, 1959, **2**, No. 214) have been amended for correlating fluidisation phenomena. These equations are compared with others for flow through porous media, fluidisation and sedimentation. W.G.C.

**34. Injection moulding: a rheological interpretation Pt. 1.** R. L. BALLMAN and H. L. TOOR, *Mod. Plast.*, 1959, 105–111. Research Dept. Monsanto Chemical Co., Springfield, Mass. The " basic problem " of injection moulding i.e. the filling of a cold cavity with a hot material has been studied theoretically and experimentally. An exponential relationship is found between the mean fluid velocity and time for cavities of constant cross section at a constant pressure for both polystyrene and polyethylene over a wide range of conditions. Part I discusses preliminary experiments, theory and the experimental problem. Part 2 will discuss equipment and results. E.B.A.

**35. Diffusion and viscosity in a spherical cavity.** S. BROERSMA, *J. Chem. Phys.*, 1959, **30**, 707—717. Dept. of Physics N.W. University Evanston, Ill., U.S.A. A general treatment of the flow pattern between two concentric spherical surfaces separated by a fluid, in which the forces required to rotate or translate the inner sphere are calculated.

Applications to the calculation of the diffusion constant for rotation or translation, viscosity of suspensions, flow in porous media etc. are discussed. E.B.A.

**36. Mobility of molecules in liquids near the glass temperature.** F. BUECHE, *J. Chem. Phys.*, 1959, **30**, 748–752. Dept. of Physics, University of Wyoming, Laramie. A model is proposed in which the radial oscillation of molecular shells elastically connected to neighbouring shells and a central molecule are considered. Movement of the central molecule will only take place if the amplitude of vibration is large enough to produce a hole into which the central molecule can jump. The jump frequency so calculated, obeys an exponential relationship with the reciprocal absolute temperature at high temperatures but conforms to the Williams Landel & Ferry relationship at low temperatures. The molecular parameters needed to fit experimental data are of the right order of magnitude. E.B.A.

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## Section B

## INSTRUMENTS AND TECHNIQUES

**37. Some aspects of viscosity determinations with capillaries.** A. POCHAN, *Chem. et Ind.*, 1959, **81**, 667–680 ; *J. Amer. Oil Chem. Soc.*, 1959, **36**, 402. Experimental results obtained by the author with thet ensiometer-viscosimeter A.R.P. (an apparatus which allows in one manipulation, at various temperatures, the absolute determination of viscosity and capillary tension of liquids) invalidate the present theory on surface tensions. As far as industrial practice is concerned, the Poiseuille law may be considered as a good approximation, but on scientific grounds a thorough study of capillary phenomena is necessary. N.W.

**38. Capillary viscometer for inert gases and vapours at high temperatures and pressures.** J. M. SAVINO and W. L. SIBBIT, *Ind. Eng. Chem.*, 1959, **51**, 551–554. Purdne University, West Lafayette, Ind., U.S.A. A coiled capillary viscometer for testing non-reacting gases, vapours and mixtures up to 815°C and 510 atmos. is described. It has been calibrated and tested with nitrogen and carbon dioxide at 25°C and pressures up to 270 and 48 atmos. respectively.

**39. Prescision viscometry of polyisobutane in toluene.** H. W. ZWEEGMAN and J. J. HERMANS, *Proc. k. ned. Akad. Wetenschap.*, 1958, **62B**, 102–108.

**40. Simple method for finding the ratio of surface tension to viscosity of a liquid.** G. M. SREEKANTATH, N. RAJARAM, and C. K. PONNAPPAN, *J. Sci. Instrum.*, 1959, **36**, 378–380. University College, Trivandrum, India. The method employs an inclined capillary tube up which the liquid is drawn by means of a manometer. Results are obtained graphically, and these are reported for water, benzene, carbon tetrachloride and nitrobenzene. W.G.C.

**41. A correlation for the Hercules, Hagan and Brookfield viscometers for a Newtonian fluid.** R. C. CHASE, *Tappi*, 1959, **42**, 97–104. Department of Chemical Engineering, University of Maine, Orono, Me.

**42. Paper test data from pendulum and inertialess testers.** R. J. CAPOTT, S. B. NEWMAN, and J. MONDEL, *Tappi*, 1959, **42**, 480–486. National Bureau of Standards, Washington, D.C.

**43. Extensometer for recording the slip of riveted joints under load.** S. A. V. SWANSON, *J. Sci. Instrum.*, 1959, **36**, 320–321. Mechanical Engineering Dept., Imperial College, London. Movement in a riveted joint is detected and measured by use of a differential transformer, and the data is used to plot load-slip curves automatically. The apparatus allows the joint area to be heated by radiation when so required.

W.G.C.

**44. Design for an autographically recording tensile machine.** M. A. ADAMS, *J. Sci. Instrum.*, 1959, **36**, 444–446. Metallurgy Division, A.E.R.E., Harwell, Berks. An improved " hard " type tensile machine is described, designed primarily for metallurgical usage. Compactness and mechanical simplicity are combined with maximum accessibility of the load measuring device and specimen, and the load is measured with an electro-mechanical dynamometer which is easily adapted into a system for autographically recording the load-elongation curve. The machine should be particularly useful for dry-box or hot-cell work. Author

**45. Apparatus for the measurement of internal friction and dynamic Young's modulus at kilocycle frequencies.** E. W. DICKSON and H. STRAUCH, *J. Sci. Instrum.*, 1959, **36**, 425–428. Tube Investments Research Labs., Hinxton Hall, near Saffron Walden, Essex. Electrostatic transducers are used to excite and detect longitudinal vibrations in a rod specimen clamped at its mid-point. The electronic circuit forms a regenerative loop in which oscillations occur at the resonance frequency of the specimen. A method of calculating the amplitude of the specimen oscillations is given. Measurements of the internal friction and dynamic Young's modulus, which can be made as a function of strain amplitude and temperature up to 500°C, are illustrated by some preliminary observations on beryllium.

Author

**46. Direct stress machine for combined fatigue and creep testing.** A. H. MELEKA, *J. Sci. Instrum.*, 1959, **36**, 468–471. British Iron and Steel R.A., London, W.1. The report described the modifications introduced to a commercial creep-testing machine so that tests under combined fatigue and creep conditions can be carried out. Results are given illustrating the performance of the converted machine. Limitations and further modifications are briefly discussed. Author

**47. A new grain hardness tester.** R. KATZ, A. B. CARDWELL, N. D. COLLINS, and A. E. HOSTETTER, *Cer. Chem.*, 1959, **36**, 393–401. Department of Physics, Kansas Agricultural Experiment Station, Manhattan. A hardness tester, especially adapted for grain, was constructed by modifying a commercial portable soft metal tester known as the Barcol Impressor. A preloaded stylus is forced into grain sections prepared by means of a microtome. The displacement of the stylus, measured by a dial micrometer, is used as a hardness index. This had been related to the Vickers diamond pyramid hardness which is a standard metallurgical test. A

number of hardness measurements may be made on a single transverse kernel section. The tester may be used for all wheat varieties. Significant variations in hardness within a single wheat kernal section have been demonstrated. While the hardness of a block of lead varied over $\pm\frac{1}{2}$ hardness number, a kernel section of hard winter (Ponca) wheat exhibited hardness numbers ranging from 25 to 40, on the arbitrary scale of this tester. H.G.M.

**48. Resistance to flow in vascular beds.** H. S. BURRY, *Nature, Lond.*, 1959, **184**, 453–454. The British Boot, Shoe and Allied Trades R.A., Satra House, Rockingham Road, Kettering, Northants. The analogy between resistance to flow and ohmic resistance as expressed by Carlill and Burton (*Rheology Abstracts*, 1959, **2**, Abs. 364) is amended by inclusion of a term to represent the critical closing pressure. An equivalent electrical circuit for comparison with vascular phenomena is detailed, and the use of a triode valve as an analogue is also suggested. W.G.C.

**49. Inductance bridge for sensitive displacement measurements over long periods.** D. MURRAY, *J. Sci. Instrum.*, 1959, **36**, 312–315. National Physical Laboratory, Teddington, Middlesex. This paper describes an application of linear differential transformers in an a.c. bridge that provides reproducible displacement measurements over long periods, extends the linear response whilst retaining high sensitivity, and can be readily adapted for automatic recording of displacement. Examples are shown and discussed of typical metal core and air core transducers mounted on N.P.L. creep extensometers. This method is sensitive to strains of the order of $10^{-6}$in. W.G.C.

**50. Injection moulding F.E.P. fluoro carbon resin.** H. A. LARSEN, G. R. DEHOFF, and N. W. TODD, *Mod. Plast.*, 1959, 89–96. Polychemicals Dept., E. I. du Pont de Nemours & Co., Wilmington 98, Delaware. A rheological factor of particular importance in moulding of fluorocarbon polymers is that the rate of shear should not exceed a critical value at which flow instability occurs, otherwise delamination occurs in the mouldings. E.B.A.

**51. An improved brittle point test for tars.** S. PICKLES, *J. Appl. Chem.*, 1959, **9**, 219–223. The Coal Tar Research Association, Gomersal, Leeds. A modification of the Fraass test (Inst. of Petroleum specification I.P. 80/53) in which the spring steel plaque is replaced by a clear polyester film to enable easy observation of the cracks by transmitted light. The flexing of the plaque is carried out by means of an electrical drive. Simple relations were obtained between the brittle temperatures so determined and the equiviscous temperatures of a series of coal tars and pitches. E.B.A.

**52. A modified Vicat type apparatus for measuring the softening point of thermo setting plastics and laminates.** G. F. EHLERS, *A.S.T.M. Bull.*, 1959, No. 236. Materials Laboratories, Wright Air Development Center. A heated aluminium block replaces the conventional oven or oil bath. This gives closer temperature control at different positions and by replacing with a cold block eliminates long cooling times. The relation between the Vicat softening point and the A.S.T.M. D.648 heat distortion temperature was found for a number of epoxy resins. E.B.A.



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**53. Visualisation of plastic flow-patterns.** R. A. COLLACOTT, *Engineering, Lond.*, 1959, **188**, 646–647. Queen Mary College, London. An analogue device which will give a visual indication of the two-dimensional flow of a plastic substance under imposed deformations has been developed. Both the apparatus and the method of working it are simple and inexpensive. Author

**54. The problem of plasticity.** H. LEHMANN and H. DUTZ, *Tonindustrztg*, 1958, **82**, 364–368. After an account of the various methods proposed for measuring the plasticity of clay-water systems, the design of a new torsional plastograph, developed at the Institut für Steine und Erden der Bergakademie Clausthal, is described. A working hypothesis is presented for determining the plasticity of clay-water systems using the torsion method, by means of which the forces leading to deformation were determined in relation to the water content and to the rate of deformation. D.P.O.

**55. Viscosity increase due to solid fat formation in tempering chocolate coatings.** W. DUCK, *Manuf. Confectioner*, 1958, **38**, 9–12, *J. Amer. Oil Chem. Soc.*, 1959, **36**, 131. To measure the percentage of solid fat (degree of tempering) in a chocolate coating, a laboratory tempering kettle-viscometer has been developed.

**56. The measurement of the hardness of margarine and fats with cone penetrometers.** A. J. HAIGHTON, *J. Amer. Oil Chem. Soc.*, 1959, **36**, 345–348. Unilever Research Laboratory, Vlaardingen, The Netherlands. In order to be able to compare the results of hardness measurements on margarine, fats, shortenings, etc., measuring both with cone penetrometers and other rheological instruments, several measurements have been made with various cones and samples. The results obtained showed that the yield value can be calculated from the following formula :

$$C = KW/p^{1.6}$$

in which $C$ = yield value
$K$ = factor dependent on the angle of the cone
$p$ = the penetration depth in 0.1 mm. at a penetration during 5 seconds
$W$ = the weight of the cone (grams).

This formula appeared to apply for cones with angles between 15 and 90° over a very wide hardness range (between 45 and 8300 g/cm²) for margarine, fat, shortening, and butter. The advantages of the proposed procedure for determining the yield value are that it is an objective measure instead of a " thumb test " ; results obtained with various cones can be compared ; and this method is highly suitable for standardizing. Author

**57. Consistency measurements on batters, doughs, and pastes.** E. B. LANCASTER and R. A. ANDERSON, *Cereal Chem.*, 1959, **36**, 420–430. Northern Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture, Peoria, Illinois. A consistency-recording apparatus, consisting of a variable voltage transformer and a recording differential ammeter, has been used with various mixers to investigate some mixing properties of a variety of batters,

doughs, and pastes over an extremely wide consistency range. Curves obtained when flour-water batters were tested have proved to be valuable in predicting the proper water-flour ratio needed for carrying out the continuous batter process for fractionating wheat flour. From these curves, it has also been possible to establish a relationship between the protein content of the flour and the consistency of the batter. The relationship, based on 41 observations, has a correlation coefficient of 0·97, and a standard error of estimate of 0·104, in terms of consistency. To demonstrate the operating range of the apparatus, it has been applied to the examination and testing of cake-mix batters, starch-water mixtures, and doughs prepared from dried gluten and soft wheat flour. H.G.M.

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## Section C

## METALS AND OTHER SOLIDS

**58. Evaluation of high temperature alloys under combined static and dynamic stresses.** P. E. HAWKES and C. H. EK, *A.S.T.M. Bull.*, 1959, No. 235, 46–50. General Motors Research Laboratories. A high frequency dynamic fatigue machine is described in which the specimen is subjected to a static tensile loading and an alternating flexural stress at elevated temperatures. The apparatus has been used to evaluate alloys used for gas turbine buckets. E.B.A.

**59. The effect of temperature interruption on an elastic creep.** J. D. LUBAHN, *A.S.T.M. Bull.*, 1959, No. 239, 61–62. General Electric Co., Schenectady, N.Y. The recovery of an elastic strain after removal of the load in a creep test on a Cr–Mo–V steel at 1000°F is not significantly affected by cooling to 80°F and reheating to 1000°F with the load on. Removal of the load at 80°F produced no time-dependent length changes. The use of pre-strained steels to counteract creep in service is mentioned. E.B.A.

**60. Strength of a grooved stud.** D. C. HERBERT, *Nature, Lond.*, 1959, **184**, 897–898. Engineering Labs., Snowy Mountains Hydro-Electric Authority, P.O. Box 332, Cooma North, N.S.W., Australia. The breaking loads of structural steel bars, which were reduced in sectional area by a circumferential groove of semi-circular cross-section, were found to be 60 per cent greater than predicted from the tensile strength of the material. The fractured specimens showed mainly brittle failure except for narrow bands of ductile failure around the edge. The results are discussed with respect to the theories of Petersen and Orowan. W.G.C.

**61. Remarks on the solid-liquid transition of certain metals.** P. H. CHOQUARD and J.-C. COURVOISIER, *Helv. Phys. Acta*, 1959, **32**, 296–302. Battelle Inst., Geneva. Using a potential function of trigonometrical form, the internal energy and specific heat are calculated as functions of temperature with particular reference to silver and gold. [French] A.S.L.

**62. High-temperature mechanical properties of graphite.—I. Creep in compression.** PAUL WAGNER and ALLEN R. DRIESNER, *J. App. Phys.*, 1959, **30**, 148. University of California, Los Alamos, New Mexico. Measurements have been made of the steady-state rates of compressive creep of graphite in the temperature range 2270 to 2780°K. Creep to failure was observed to occur in one of two ways ; three out of seventeen samples exhibited a third stage of creep before failure occurred, the remaining fourteen samples failed in a manner analogous to that observed for graphite in tension, that is fracture without the appearance of a third stage. All the latter type creep data are correlated by a classical rate equation of the form : rate $= K(\sigma/\sigma_b)^n \exp(-E/RT)$. Author

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**63. High-temperature properties of graphite.—II. Creep in tension.** PAUL WAGNER, ALLEN R. DRIESNER, and LARRY A. HASKIN, *J. App. Phys.*, 1959, **30**, 152. University of California, Los Alamos, New Mexico. Measurements have been made on the steady-creep rated of graphite in tension in the temperature range 2270° to 3270°K. Moulded, extruded and uranium " loaded " graphites were used in the course of investigation. The general characteristics of creep in graphite at high temperatures have been described in the literature and the results presented here covering the range of steady-state creep $10^{-1}$ to $10^{-4}$cm/sec are in accord with published results. In addition, the tensile steady-state creep data are correlated by a classical rate equation of the form, rate $= f(U)(\sigma/\sigma_b)^n \exp(-E/RT)$, where $f(U)$ is a function of the uranium concentration in the graphite. Author

**64. An electron microscope study of synthetic graphite.** I. M. DAWSON and E. A. C. FOLLETT, *Proc. Roy. Soc.*, *A*, 1959, **255**, 390–402. Department of Chemistry, The University, Glasgow, W.2.

**65. Creep tests in Antarctic glacier ice.** M. MELLOR, *Nature, Lond.*, 1959, **184**, 717. Meteorology Department, University of Melbourne, Victoria, Australia. The results of compression creep tests in the stress range 2–15 bars on randomly orientated antarctic ice at −30°C agree with the simple flow law derived by Glen. The easier deformation at a given stress and temperature from that predicted by the rate of strain-temperature relationship of Glen is attributed to the presence of small (0·6 mm diameter) air bubbles in the ice. W.G.C.

**66. Solid state rheological study of the mechanism of paraffin-detergent interactions in aqueous systems.** F. J. RADD and L. H. CROWDER, *Nature, Lond.*, 1959, **184**, 443–444. Continental Oil Co., P.O. Drawer 1267, Ponca City, Oklahoma, U.S.A. Tensile specimens of paraffin wax, prepared by pouring liquid paraffin on to a clean, hot water surface, were extended at 0·50 in/min in an " Instron " precision tension test instrument. Four representative specimens were tested in each of three environments : distilled water, 0·4 per cent sodium lauryl sulphate solution in distilled water, and 0·4 per cent sodium dodecyl benzene sulphonate solution in hard water. The presence of the detergent solutions was found to decrease the elongation of the test specimens. This is attributed to the wetting effects of the detergent molecules in that they probably prevent repair

of extremely fine surface cracks ; these cracks only being observed in the detergent-immersed specimens. Industrial aspects of the paraffin-detergent interaction are considered. W.G.C.

**67. Factors contributing to the strength of a sheet of paper.** E. F. THODE and W. L. INGMANSON, *Tappi*, 1959, **42**, 74–93. Chemical Engineering Group, Institute of Paper Chemistry, Appleton, Wis.

**68. Testing the tearing resistance of paperboard.** H. W. VERSEPUT and W. R. NAISET, *Tappi*, 1959, **42**, 406–409. Research and Development Dept., Robert Gair Paper Group, Continental Can Co. Inc., Uncasville, Conn.

**69. Mechanical properties of wood fibres.** B. A. JAYNE, *Tappi*, 1959, **42**, 461–467. Division of Industrial Research, Washington State Institute of Technology, State College of Washington, Pullman, Wash.

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**70. The influence of direction of loading on the strength of concrete test cubes.** A. M. NEVILLE, *A.S.T.M. Bull.*, 1959, No. 239, 63–65. University of Manchester, England. It is found that when cubes are tested for compressive strength there is no significant difference between tests made parallel and perpendicular to the casting direction provided there is no segregation of the components and the applied load is distributed uniformly over the surface. E.B.A.

**71. Cracks on reinforced concrete beams.** B. KOTLEGA and J. LEMPICKI, *Arch. Inzy. Ladowej, Warsz.*, 1958, **4**, No. 4, 493. Stress strain relations and reinforcement parameters and their effect on crack formation are discussed from the practical point of view. [Polish] P.F.

**72. Statistical methods for determining the degree of non-homogeneity of concrete.** M. VORLICEK, *Arch. Inzy. Ladowej, Warsz.*, 1958, **4**, No. 4, 537. [Polish]

**73. The strength of concrete with various shapes and dimensions of test-pieces.** W. KUCZYNSKI, *Arch. Inzy. Ladowej, Warsz.*, 1959, **5**, No. 2, 139. A report is made on extensive statistical tests concerning the effect of shape and size of test samples on the strength of concrete in compression. [Polish] P.F.

**74. Texture and flow properties of brick materials.** I. HOMAYR, *Ziegelindustrie*, 1958, **11**, 199–203. Flow curves can be of considerable value in interpreting the processes taking place during brick moulding, and further practical tests concerning the flow properties of material are envisaged. D.P.D.

**75. Strength impairment mechanism of glass in aqueous systems.** F. J. RADD and D. H. OERTLE, *Nature, Lond.*, 1959, **184**, 976. Continental Oil Co., P.O. Drawer 1267, Ponca City, Oklahoma, U.S.A. Tensile strength studies of commercial glass fibres have shown that the fibres are weakened by exposure to water and that this effect is increased by high pH solutions. These results substantiate previous empirical data in the literature, and confirm the view that the observed impairment is due to chemical solution. W.G.C.

**76. Strength of glass fibres.** J. G. MORLEY, *Nature, Lond.*, 1959, **184**, 1560. Rolls-Royce Ltd., Aerophysics Lab., Littleover, Derby. An attempt has been made to eliminate the effect of surface discontinuities on the tensile strength of glass fibres by producing specimens coated with a glass which at elevated temperatures behaves as a viscous liquid whilst the core remains a brittle solid. The results for these fibres with diameters between 0·002 and 0·010 in. show great variability, but the maximum tensile strength values of the coated fibres was found to be several times greater than that of uncoated specimens. W.G.C.

**77. Prestressed beams with glass fibre reinforcement.** S. KAJFASZ, *Arch. Inzy. Ladowej, Warsz.*, 1959, **5**, No. 3, 321. Reinforcement of concrete beams by glass cords was studied. The results were disappointing. Causes of the weakness of the glass reinforcement and possible ways of remedying this are discussed. [Polish] P.F.

**78. Shear effects in glass fibre reinforced plastic laminates.** R. E. CHAMBERS and F. J. MCGARRY, *A.S.T.M. Bull.*, 1959, No. 238, 38–41. M.I.T. By simple bending tests over span-depth ratios of 7 to 20 the variation in apparent flexural modulus has been shown to result from interlaminar shear stresses set up by the applied central load. The interlaminar shear modulus approximates the shear rigidity of the pure resin. True flexural modulus is the average of the tensile and compressive modulus, as expected. The variations of apparent flexural strength with span-depth ratio appears to be related to the tensile ductility of the laminating resin, and the apparent flexural strength depends primarily upon the strength characteristics of the resin. Author

**79. Tensile and compressive properties of fibreglass reinforced laminates.** R. E. CHAMBERS and F. J. MCGARRY, *A.S.T.M. Bull.*, 1958, No. 233, 40–44. Massachusetts Institute of Technology. Laminates were tested in bending, compression and testing and the strains at various positions within the laminate measured with gauges which were banded into the laminates during manufacture. It was found that partial internal failure occurred during tensile straining at stresses that were low compared with the ultimate strength of the material. Failures of this kind do not appear during compressive loading. The stress and strain distributions in a flexural test specimen departed strongly from classical theory. Internal failures result in an increase in water absorption of the laminate.

E.B.A.

**80. Time dependence of mechanical breakdown in bundles of fibres. —V. Fibres of Class A-2.** BERNARD D. COLEMAN, *J. App. Phys.*, 1959, **30**, 720. Mellon Institute, Pittsburgh 13, Pennsylvania. The theory of mechanical breakdown in bundles of Class A-2 fibres, whose strength depends on the speed of measurement, is used to find the conditions under which time-dependence effects can be neglected in calculations of relationships between the strength of bundles and the strength of their constituent filaments. (The classical theories of the strength of bundles do not consider time dependence.) Tables and graphs are presented which give the ratio, $R$, of the strength of an infinite ideal bundle to the mean strength of its filaments as a function of the coefficient of variation,

$R_1/E_1\{f^*\}$, in the strength of the filaments. It is shown that, under certain limiting conditions, $R$ for an infinite bundle of Class $A$-2-fibres is the same as it would be for an infinite bundle of classical fibres with an equal value of $R_1/E_1\{f^*\}$, and a numerical investigation is made of the rapidity with which this limiting behaviour is approached.

Author

## Section D

## POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

**81. The testing of plastic pipes.** Report by six West German Companies (six authors), *Plastics* (*Lond.*), 1959, **24**, 147–156. Present results of investigations to establish reliable data concerning the permissible maximum pressures for tubes of rigid P.V.C. and high and low density polyethylenes, and minimum values of creep rupture strength for quality control. A considerable number of curves are presented, and long term extrapolation techniques and quality control methods are discussed.

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**82. Non-Newtonian viscosity of synthetic rubber and its solutions.** F. BUECHE, *J. App. Phys.*, 1959, **30**, 1114. University of Wyoming, Laramie, Wyoming. The variation of viscosity $\eta$ with shear rate $\gamma$ was measured for a solution of a milled synthetic rubber GRS-1006 in diethyl benzene. A cone viscometer was used for concentrations 13–50 per cent and a concentric cylinder viscometer for concentrations 50–100 per cent. When $\log(\eta/\eta_o)$ is plotted vs. $\log(\gamma\%/TC)$ the experimental points fit on the universal curve previously found for polystyrene and polymethyl-methacrylate showing that rubber behaves in the same way as these other polymers. It is concluded that the mechanism of flow in these systems is covered by the same molecular theories for viscoelasticity in high polymers.

G.H.T.

**83. Mooney cure tests for calculating curing times.** A. E. JUVE, *A.S.T.M. Bull.*, 1959, No. 239, 71–75; also *Rubber World*, 1959, **140**, 705–710. B. F. Goodrich Research Center, Brecksville, Ohio. The rise in Mooney viscosity of a rubber stock after the initial fall, which is usually used to indicate "scorch time" can also be used as a guide to the optimum curing time for the compound, if the rate of rise is measured with the required degree of accuracy. When fast curing stocks are used a correction must be applied for the rate of attainment of the test temperature.

E.B.A.

**84. Mechanochemical phenomena in polymers.—Part 1. Chemical flow in raw and vulcanised rubbers.** G. L. SLONIMSKI and E. V. REZTSOVA, *Zhur. fiz. Khim.*, 1959, **33**, 480–486. [Russian] English summary 486.

**85. Viscoelastic behaviour of greases.** E. O. FORSTER, J. J. KOLFENBACH, *N.L.G.I. Spokesman*, 1959, **23**, 215–230. Esso Research & Engineering Co., U.S.A. Measurements of the behaviour of two greases subjected to sinusoidal deformations have been made at frequencies ranging from

$10^{-4}$ to 10 cycles per second. The results confirm earlier findings that greases are viscoelastic materials. The distribution of relaxation times for the greases have been deduced, and evidence has been obtained of the existence of three different types of relaxation mechanisms. A.D.B.

**86. Solid polyurethane elastomers.** S. H. MORRELL, *Research* (*Lond.*), 1959, **12**, 315–321. R.A.B.R.M. Shawbury, Shrewsbury, England. A review of solid elastomeric polyurethanes including casting and processable rubbers, together with results of physical tests obtained at the R.A.B.R.M. on typical commercial materials. Tests included tensile strength, elongation, abrasion and oil resistance, and the effect of temperature on modulus and resilience. Applications of the materials are discussed. E.B.A.

**87. On the flow birefringence of polystyrene.** H. JANESCHITZ-KRIEGL, *Makromol. Chemie*, 1959, **33**, 55–84 (Centraal Lab., T.N.O., Delft). Using the concentric glass cylinder apparatus (gap 0·25 mm) recently developed by the author, $\Delta n$ and $X$ (magnitude and extinction angle of flow birefringence) are measured for two polystyrene samples (MW $3 \times 10^6$ and $3{\cdot}3 \times 10^5$) in four solvents (bromobenzene, chlorobenzene, cyclohexanone, dioxane) at concentrations in the range 0·5 per cent to 25 per cent. Solvent birefringence is measured and allowed for. Viscosities are measured in a capillary viscometer and checked (in the case of the higher viscosities) with a rotational viscometer. The birefringence/shear stress ratio, extrapolated to zero shear rate, is independent of concentration for the solution in bromobenzene, whose refractive index is close to that of the polymer; this ratio gives a value of $-137 \times 10^{-25}$ cc for the difference of principal polarizabilities of the equivalent random link. With the other solvents, the value of the ratio at first decreases with increase of concentration and becomes independent of concentration at a value of the concentration which is greater the bigger the difference of solute and solvent refractive indices. The variable part of the ratio (i.e. at low concentrations) is attributed to form birefringence, which, estimated in this way, agrees fairly well with the value calculated from polymer molecular weight, intrinsic viscosity, and refractive index difference according to the theory of Copic and of Tsvetkov *et al*. For the solutions at 25 per cent concentration, the stress-optical coefficient $\Delta n \text{ Sin } 2\chi/[q(\eta-\eta_0)]$ ($\eta$ and $\eta_0$ = solution and solvent viscosities) is independent of shear rate $q$ in the measured range (3 to 35 $\text{sec}^{-1}$). The dependence of extinction angle on concentration does not agree with that given by existing theories. [German] A.S.L.

**88. Emulsion polymerization of styrene.** G. M. BURNETT and R. S. LEHRLE, *Proc. Roy. Soc., A*, 1959, **253**, 331–348. Chemistry Department, University of Birmingham.

**89. Segmental motion in polybutene.—I.** A. E. WOODWARD, J. A. SAUER and R. A. WALL, *J. Chem. Phys.*, 1959, **30**, 854–855. Pennsylvania State University. The mechanical loss and dynamic elastic modulus for polybutene-1 were measured between 80°K and 400°K using rod specimens driven at their first transverse modes. Three transition regions were found centred about the following temperatures: 150°K (3160 cps)

attributed to the effect of side chain motions 300°K (850 cps), the principal amorphous phase transition region, and 7400°K (crystallite melting).
E.B.A.

**90. The radiation-induced polymerisation of isobutene.** W. H. T. DAVISON, S. H. PINNER and R. WORRALL, *Proc. Roy. Soc., A*, 1959, **252**, 187–196. Tube Investments Research Laboratories, Cambridge, England.

**91. Pressure dependence of the viscoelastic behaviour of polyisobutylene.** HARKRISHAN SINGH and A. W. NOLLE, *J. App. Phys.*, 1959, **30**, 337. Department of Physics, The University of Texas, Austin 12, Texas. The absorption of 4mc/sec ultrasonic waves in polyisobutylene is measured as a function of temperature, for various pressures. The extreme limits of these variables are 1 to 1400 atmos and −20°C to 80°C, respectively. Approximate measurements of propagation velocity are also obtained. Pulse reflection apparatus is used. A magnetically actuated holder places the sample in the signal path or removes it. Pressure-volume data are obtained for polyisobutylene at 30°C by means of a capillary dilatometer fitted with electrical contacts, in which the sample is placed with mercury. The expected behaviour of viscoelastic relaxation times with temperature and pressure is computed by adapting a theory due to Bueche. With additional assumptions concerning the compressibility, the theory gives a shift of the constant-frequency absorption maximum of 0·025C°/atmos, in approximate agreement with experiment. Author

**92. Long-term behaviour of drinking water from Ziegler-polythene.** K. RICHARD, E. GAUBE and G. DIETRICH, *Plastics, Lond.*, 1958, **23**, 444–446. Farbwerke Hoechst A.G., Frankfort/Main. Creep and rupture curves for times up to 10,000 hours are given for high density polythenes stressed by uniaxial tension and by internal pressure in tubes. The various types of fracture phenomena are described and the influence of molecular weight and surface active agents on these are discussed. E.B.A.

**93. Ziegler-type polyethylene.** M. N. BERGER and T. H. BOULTBEE, *J. Appl. Chem.*, 1959, **9**, 490–500. Shell Chemical Co., Urmston, Manchester. An account of the production of Ziegler type high density polythenes which includes curves relating molecular and chemical constitution to softening point, melt index, impact strength, yield strength etc.
E.B.A.

**94. Some experiments on the flow properties of polythenes.** R. W. HOGG, *Plastics Lond.*, 1959, **24**, 69–72. The Metal Box Co. Flow properties, softening points, cold shear strength and behaviour in the spiral flow mould flow test were studied for some high and low density polythenes. Flow properties were measured in a Melt Index grader and a Macklow-Smith plastometer. The variation of the flow curve exponent $\eta$ at 190°C with the melt index of the sample (determined under a constant shear stress conditions) was distinct for the high and low density materials. $\eta$ also varied in a different way for the two types of polythene with extrusion pressure. E.B.A.



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**95. Polythene–mechanism of fracture.** P. L. CLEGG, S. TURNER and P. I. VINCENT, *Plastics, Lond.*, 1959, **24**, 31–36. I.C.I. Plastics Division, Welwyn Garden City, Herts, England. Tough and brittle failure of polythene is discussed in relation to the conditions of temperature and stress under which they occur. Thermal effects during "cold" drawing, impact tests, low temperature brittleness tests, bursting and tearing tests on films and long-time failures under stress are related to the polymer density and morphology and processing conditions used. E.B.A.

**96. Creep and stress-rupture behaviour of polythylene resins.** R. H. CAREY, *Ind. Eng. Chem.*, 1958, **50**, 1045–1048. Bakelite Co., Division of Union Carbide Corp., Bound Brook, N.J. Data obtained with a simple apparatus to evaluate plastics for long-time load-bearing applications are discussed. The great effect of degree of crystallinity on creep behaviour is emphasised. R.H.B.

**97. Influence of temperature on viscosity of polyethylene.** J. MAJER, *Chem. prumysl.*, 1959, **9**, 219–220. [Czech] English summary 220.

**98. Polypropylene.** G. CRESPI and F. RANALLI, *Trans. Plast. Inst. Lond.*, 1959, **27**, 55–73. Montecatini SPA, Italy. The article gives a considerable amount of information on the physical properties of this of this polymer, in relation to the isotactic index and melt index. Properties discussed include elastic modulus, strength properties, softening behaviour brittle point, ultrasonic velocity and "mouldability" in injection moulding tests. E.B.A.

**99. Moulding and forming the new polyolefins.** R. D. HANNA and J. Y. LOMAX, *Mod. Plast.*, 1959, 111–122. Hercules Powder Co., Parlin, N.J. Gives Enthalpies, specific volumes and shear-rate/shear-stress curves for most of the processing temperature range for polypropylene and high density polyethylene. E.B.A.

**100. Radiation-induced changes in the structure of polypropylene.** R. M. BLACK and B. J. LYONS, *Proc. Roy. Soc., A*, 1959, **253**, 322–330. British Insulated Callender's Cables Limited Research Organization.

**101. Mechanical-dynamic properties of polymers of some methacrylates.** E. BUTTA, *Ann. Chim. (Italy)*, 1959, **49**, 566–573. [Italian]

**102. Non-Newtonian behaviour of concentrated solutions of poly(vinyl alcohol).** H. MAEDA, T. KAWAI and Y. SAITO, *J. Chem. Soc., Japan*, 1959, **80**, 243–250. [Japanese] English summary, A18

**103. Vinyl chloride polymers : their design and application.** B. S. DYER, *Trans. Plast. Inst. Lond.*, 1959, **27**, 84–93. I.C.I. Plastics Division, Welwyn Garden City. Describes how the molecular geometry of the polymer and the physical form of the polymer particles influence the way in which it behaves during processing. Compounding of plasticised P.V.C. in a Banbary mixer was studied by following changes of temperature and rotor torque during the mixing cycle and correlating these with photo-micrographic examination of the compound to reveal changes in

dispersion. Other subjects treated include the rheological requirements of a compound for moulding gramophone records and the influence of particle geometry upon P.V.C. " paste " dispersions. E.B.A.

**104. Injection moulding of rigid P.V.C.** C. A. BRIGHTON, *Brit. Plast.*, 1958, **31**, 468–472. British Geon Ltd., Barry, Wales. Includes data on flow properties of P.V.C. polymers and results of " spiral mould flow tests " on P.V.C. compounds of different intrinsic viscosity. The effect of milling time on the flow properties of P.V.C. compositions was studied.

**105. Rotational casting of P.V.C. pastes.** A. C. MEAZEY, *Brit. Plast.*, 1959, **32**, 55–59. British Geon Ltd., Barry, Glamorgan, Wales. The success of this process depends largely upon the rheological properties of the paste. Curves are given for dependence of viscosity on composition of resin blends, per cent plasticiser and temperature. E.B.A.

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**106. Effect of small quantities of plasticisers in P.V.C. compounds.** P. GHERSA, *Mod. Plast.*, 1959, 135–142. Pirelli, SpA, Milan. Incorporation of small amounts of a plasticizer in a polyvinyl chloride resin (less than 10 per cent by weight) make the compound harder and more rigid, and not more flexible as might be expected. The effect of plasticiser on tensile strength, elongation, impact strength and tensile modulus is anomalous in the range of plasticiser concentrations of 0–20 per cent. Softening of the resin by the plasticiser only takes place beyond a certain critical concentration. The effect is attributed to steric hindrance of plasticiser molecules attached to the P.V.C. chains, and the more polar plasticisers give more pronounced anomalies. E.B.A.

**107. Rheological investigations of macromolecular substances.—Part 4. Rheological investigations of poly(vinyl chloride) pastes. (2) Effect of temperature on poly(vinyl chloride) pastes.** Z. CSUROS, M. GROSZMANN, I. GECZY and K. JUHASZ, *Acta Chim. Acad. Sci. Hung.*, 1959, **19**, 65–73. [German]

**108. Effect of moulding temperature on the time of moulding and type of mechanical-dynamic properties and structure of phenol-formaldehyde resins.** M. BACCAREDDA snd E. BUTTA, *Ann. Chim. (Italy)*, 1959, **49**, 548–558. [Italian]

**109. The degree of polymerization and its distribution in cellulose rayons.—Part IX. The influence of distribution of degree of polymerization on the mechanical properties of monofilaments.** R. J. E. CUMBERBIRCH, *J. Text. Inst.*, 1959, **50**, T528. British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester, 20. Oriented cellulose filaments of known distribution of degree of polymerization (D.P.) were prepared from mixtures of well-characterised fractions of secondary cellulose acetate. The birefringence of the filaments was used as an index of orientation. Measurements of the tenacities and breaking extensions of these filaments were made and compared with the results of similar measurements on filaments from commercially produced rayons of known distribution of D.P. A method for computing the tenacity of a filament from the distribution of D.P. and the tenacities of filaments produced from homogeneous fractions of known D.P. is discussed. D.W.S.

**110. A molecular approach to the problem of viscoelasticity.** A. H. NISSAN and H. G. HIGGINS, *Nature, Lond.*, 1959, **184**, 1477–1478. Dept. of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York. The validity of a basic hypothesis, that the mechanical properties of such materials as paper, regenerated cellulose and ice are controlled by the number of hydrogen bonds per unit volume of material and by the potential energy of these bonds, is demonstrated. Results obtained from simple tension experiments are discussed for the particular case of paper sheets prepared from high $\chi$-cellulose content eucalypt pulp which had been acetylated to various extents. It is deduced that the substitution of a hydrogen atom by the larger group on acetylation not only reduces the number of hydrogen bonds but opens up the structure. It also appears that the number of OH groups available for acetylation is larger than the number required to participate in hydrogen bonding. W.G.C.

**111. Synthetic yarns under constant load.** H. BIEDERMANN and E. GEIGER, *Helv. Chim. Acta*, 1959, **42**, 1870–1877 (Steckborn Kunstseide AG). Extension is measured as a function of time for viscose yarn and nylon cord under constant load. Breaking load and time to break are also measured. [German] A.S.L.

**112. Mechanics of nonwoven fabrics.** D. R. PETTERSON, *Ind. Eng. Chem.*, 1959, **31**, 902–903. Research Division, Chicopee Manufacturing Corp., Milltown, N.J.

## Section E

## PASTES AND SUSPENSIONS

**113. Flow of dense pastes in vertical tubes.** S. CALVERT and R. H. MILLER, *Ind. Eng. Chem.*, 1958, **50**, 1793–1798. Engineering Research Institute, University of Michigan, Ann Arbor, Mich. The flow characteristics of high density pastes were observed for systems in which solid particles are conveyed at the highest possible packing density. R.H.B.

**114. Studies on the rheology of suspensions of raw materials containing clay minerals.** H. LEHMANN and G. MARX, *Torindustrztg*, 1958, **82**, 354–364. The design of a Couette-type viscosimeter for use with clay mineral suspensions is described. A working hypothesis is derived from test results to analyse the forces governing rheological behaviour, and the concept of plastic flow is proposed as an alternative to structural viscosity. It is possible from the measurements to predict the thixotropy, the plastic flow, the stability, the casting properties and the ageing of the suspended clay-minerals ; the properties of the ware, its thickness and setting time, can also be determined from the flow curves. From the flow curves obtained with the new viscosimeter a simple relationship is established between the resulting decrease in velocity and the shear stress, from which it is possible to determine the degree of stability of the suspension. 43 references are given.

**115. Investigations on the plasticity of clays and kaolins.** E. SCHARRER and U. HOFFMANN, *Ber. Dtch. Keram. Ges.*, 1958, **35**, 278–285. The instrument described was designed to measure the tensile strength and the deformation pressure of damp extruded clay at different water contents. Measurements made on 18 kaolins and clays. From the results obtained plasticity parameters were derived that are basically expressions of the ratio of the tensile strength to the resistance to deformation. These parameters were composed with the plasticities according to Pfefferkorn, Attenberg and Rieke and considered in relation to the water-content at the yield point, the particle size distribution and the cation-exchange capacity. The measurements of the tensile strength and deformation pressure were in good agreement, and this method of investigation is recommended as reliable for studying the plastic behaviour of clays and kaolins.

**116. Efficient principle for controlling the viscosity and static pressure of dislocation of drilling muds.** S. IU. ZHUKHOVITSKII, *Neftyanoe Khoz.* (February, 1959), **37**, 38–44. [Russian]

**117. Rheology in the cement industry.** M. PAPADAKIS, *Silicates industr.*, 1958, **22**, 675–681.

**118. Dynamics of solutions of macromolecules in a range of velocities. Estimate of actual possibilities.** R. CERF, *Fortschr. Hochpolym.-Forsch.*, 1959, **1**, 382–450. [French]

**119. The non-Newtonian characteristics of lubricating oils.** T. W. SELBY, *A.S.L.E. Trans.*, 1958, **1**, 68–81. General Motors Technical Centre, Warren, Michigan. In this paper the author discusses the viscometry of mineral oils and mineral oil-polymer blends at moderate temperatures and high shear and at low temperatures and low shear. The non-Newtonian influences of two common polymeric additives, polyalkylmethacrylate and polyisobutylene, are shown to vary considerably at low temperatures in their effects on a common base oil. Shear dependence of polymer containing oils at high shear rates is experimentally indicated to reduce the viscosity of the blend to approximately that of the base oil. Conclusions of practical interest are drawn from the experimental results. Author

**120. The visco-elastic behaviour of lubricating oils under cyclic shearing stress.** A. J. BARLOW and J. LAMB, *Proc. Roy. Soc., A*, 1959, **253**, 52–69. Electrical Engineering Department, Imperial College, London, S.W.7. The shear mechanical impedance of three base-stock lubricating oils has been measured as part of an investigation into the influence of relaxation behaviour on lubrication. The oils selected were of high, medium and low viscosity index. In addition, results are given for a range of polydimethylsiloxane (silicone) liquids. Authors

**121. Plasometric measurement of flow properties of lubricating greases.** B. YAMAGUCHI and T. OKI, *NLGI Spokesman*, 1959, **23**, 274–281. Tokyo University, Japan. A parallel plate plastometer was used to determine the flow properties of lubricating greases. It was found that every sample of grease tested showed the phenomenon of creep. No direct relationship

was found between the ASTM penetration and the value of Nuttings' firmness function which was found to fit the data. Measurements of syneresis (oil loss) were compared with those of creep at a given load and it was found that syneresis proceeds in direct proportion to creep.
A.D.B.

**122. Effect of thickener-particle dimensions on lubricating grease properties.** A. C. BORG and R. H. LEET, *Lubric. Engng.* (1959), **15**, 450–453. Standard Oil Co., Whiting, Indiana. A brief study is made of the effect of length-to-width (L/W) ratio of the soap particles on the sensitivity to consistency changes of four greases on ageing and in two types of mechanical tests. The changes in consistency in all treatments were smaller the greater the L/W ratio. The soap stock used was lithium hydroxystearate. J.F.H.

**123. The flow of lubricating greases.** A. W. SISKO, *Ind. Eng. Chem.*, 1958, **50**, 1789–1792. Standard Oil Co. (Indiana), Whiting, Ind. The flow of lubricating greases in capillaries is investigated experimentally over a wide range of shear ratio. The Buckingham equation and the three-parameter Ree-Eyring equation were found to be inadequate and an empirical three-parameter equation is proposed to represent the experimental data. R.H.B.

**124. Progress report on an investigation of the fundamental factors determining coating colour viscosities.** V. F. MATTSON and J. R. LEIGHTON, *Tappi*, 1959, **42**, 1–5. Research Dept., Oxford Paper Co., Rumford, Me. Experimental evidence is adduced to suggest that the viscosities of high-solids starch-clay coating colours can be interpreted in terms of Robinson's equation. R.H.B.

**125. The dispersion of pigments for coating colour : concept and theory.** J. V. ROBINSON, *Tappi*, 1959, **42**, 432–438. Mead Corp., Chillicothe, Ohio. Dispersion is described in terms of deflocculation and disaggregation. The progress of dispersion is deduced from the changes of " relative sediment volume ". On a diagram plotting solids content against relative sediment volume composition and consistency are related to a line representing the case of a packed sediment. By means of this " dispersion diagram " the behaviour of particles in a typical dispersion sequence may be explained. R.H.B.

**126. The reversible and irreversible thickening of stirred partially fused mixtures of R.D.X. and T.N.T.** W. O. WILLIAMSON, *J. Appl. Chem.*, 1959, **9**, 120–126. Division of Industrial Chemistry, C.S.I.R.O., P.O. Box 4331, Melbourne, Australia. Suspensions of R.D.X. in molten T.N.T. show a progressive thickening or stirring which is partially reversible. Factors which cause these phenomena are recrystallisation of the R.D.X. causing larger plane faces and formation of aggregates at the surface of the stirrer. E.B.A.

**127. Dependence of the structural and mechanical properties of copper ferrocyanide sols on the conditions of preparation.** I. F. KARPOVA and T. P. SPASIBENKO, *Vestinik Leningrad Univ.*, 1958, No. 16, 126–133. [Russian] English summary 133.

**128. The flow of blood through narrow tubes.** M. REINER and G. W. SCOTT BLAIR, *Nature, Lond.*, 1959, **184**, 354. Israel Institute of Technology, Haifa, Israel. From the integration of the Casson equation (cf. *ibid.*, 1959, **183**, 613 ; *Rheology Abstracts*, 1959, **2**, Abs. No. 350), it is shown how the constants $k_0$ and $k_1$ may be determined.

**129. Physical properties of lysolecithin and its sols.—Part 3. Viscosity.** N. ROBINSON and L. SAUNDERS, *J. Pharm. Pharmacol.*, 1959, **11**, 291–296.

**130. Viscosity of concentrated orange and grapefruit juices.** GEORGE H. EZELL, *Food Tech.*, 1959, **13**, 9–13. Florida Citrus Experiment Station, Lake Alfred, Florida. Citrus concentrates were shown to be non-Newtonian, thixotropic liquids.

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**131. Some aspects of the rheology of milk gel.** C. S. LANDAU, *Brit. J. Appl. Phys.*, 1959, **10**, 476. Ministry of Supply, Farnborough, Hants. Observations of the flow of milk gel are shown to agree with Graham's theory of deformation in that creep curves are described by the sum of powers of time ($t^{\frac{1}{2}}$, $t$ and $t^2$). The effect of stress is described by the sum of power terms with simple exponents. The strain recovered after removal of stress is proportional to $t^{\frac{1}{2}}$. The predicted hysteresis loops agree with those observed with repeated loading. C.M.J.

**132. Hardness of butter.—II. Influence of setting.** J. M. DE MAN and F. W. WOOD, *J. Dairy Sci.*, 1959, **42**, 56–61. Department of Dairying, Univ. of Alberta. The extent of setting, which is defined as the hardness increase during storage of the butter, was measured for butters made by the conventional process and by a continuous process. The effect of temperature and initial hardness was also investigated.

**133. The spreading properties of table margarines.—I. General considerations and the rheologic aspect of the problem.** M. NAUDET, E. SAMBUC and P. DESNUELLE, *Rev. franc. corps gras*, 1959, **6**, 4–9 ; *J. Amer. Oil Chem. Soc.*, 1959, **36**, 359. Fac. Sci., Marseilles. The work of the "Iterg" on practical methods for the measurement of the plasticity of fats and concrete emulsions is reviewed, Definitions are given for hardness, consistency, etc., and the methods employed for their determinations in the laboratory are reviewed. 17 references. [French]

**134. The spreading properties of table margarines.—II. Study of a needle penetrometer and a cone penetrometer.** E. SAMBUC and M. NAUDET, *Rev. franc. corps gras*, 1959, **6**, 10–17 ; *J. Amer. Oil Chem. Soc.*, 1959, **36**, 359. Fac. Sci., Marseilles. Twelve margarine samples were tested in the penetrometer of Fryer, *et al.*, and in the A.S.T.M. apparatus (A.T.S.M. D.217, 44T). Instructions are given for the preparation of samples and use of the apparatus. [French]

**135. The spreading properties of table margarines.—III. Study of two rheometers.** E. SAMBUC and M. NAUDET, *Rev. franc. corps gras*, 1959, **6**, 18–24 ; *J. Amer. Oil Chem. Soc.*, 1959, **36**, 359. Fac. Sci., Marseilles.

Consistency of margarines is determined, respectively, as the force necessary to extrude it through an orifice and by the sectilometer of Mohr, whereby the force used when cutting the sample with a steel wire is measured. Conditions are determined for obtaining agreement in results. (C.A.53, 8468.) [French]

## Section F

## LIQUIDS

**136. Flow of liquid hydrocarbons in porous Vycor.** P. DEBYE and ROBERT L. CLELAND, *J. App. Phys.*, 1959, **30**, 843. Baker Laboratory of Chemistry, Cornell University, Ithaca, New York. Experimental investigation of the flow rates of normal paraffins in porous Vycor glass shows that there are deviations from the viscosity dependence required by Poiseuille's law. A discussion of the application of capillary models to describe flow in porous media in terms of the measured porosity and surface-to-volume ratio points out that such models are not generally applicable, though they give useful results for some purposes. An estimate of the permeability predicted by Poiseuille's law is made by an empirical method which uses gas flow measurements in the Knusden flow region. The equations of slip flow as derived for gases do not explain the experimental deviations from Poiseuille flow. The concept of a slipping absorbed layer of molecular thickness at the wall of a capillary is combined with the usual Poiseuille treatment for the interior to give a result which is compatible with experiment. Author

**137. Viscosity measurements on polymer modified oils.** VLADIMIR PHILIPPOFF, *A.S.L.E. Trans.*, 1958, **1**, 82–86. The Franklin Institute, Philadelphia 3, Penn. The experimental check described proved that viscosity measurements on polymer modified oils with rotational and capillary viscometers can be successfully correlated. The rules for this are the same as those used for other non-Newtonian liquids (solutions of high polymers) ; namely, viscosity vs. the rate of shear at the wall, $R$. This is valid to at least $10^6$ sec.$^{-1}$ Author

**138. Temperature–pressure–structure effects on the viscosity of several higher hydrocarbons.** D. A. LOWITZ, J. W. SPENCER, W. WEBB and R. W. SCHIESSLER, *J. Chem. Phys.*, 1959, **30**, 73–83. Socony Mobil Laboratories, Paulsboro, N.J. Fourteen high molecular weight hydrocarbons were used, viscosities being measured at six temperatures between 37·78°C and 135°C and at pressures up to 3400 bars, with a rolling ball viscometer. P.V.T. data were determined for liquids where this was not available. The hydrocarbons were of various structural types and ranged in molecular weight from 268·5 to 535. The structure was correlated with viscosity, rate of change of viscosity with pressure, and euthalpy of activation. E.B.A.

**139. Viscosities of some undercooled liquid alkyl halides.** D. J. DENNEY, *J. Chem. Phys.*, 1959, **30**, 159–162. Brown University, Providence, Rhode Island, U.S.A. The viscosities of *iso* butyl bromide, *iso* amyl bromide and

*iso*butyl chloride have been measured over a temperature range in which $\eta$ changes from $10^2$ poise to about $10^8$ poise. The temperature dependence of $\eta$ is very close to that of the dielectric relaxation time $\tau$ indicating the similarity of the molecular processes involved. This similarity thus appears to apply to " non-associated " polar liquids as well as to hydrogen bonded liquids. Author

**140. Rheology.** W. MESKAT, *Z. Ver. dtsch. Ing.*, 1958, **100**, 1370–1374. The developments in rheology in 1957–1958 are described and a bibliography of 179 international references is given under the following headings : theoretical work, methods of measurement and procedures, results of measurements, rheological properties of lubricating oils and greases, viscosity and molecular weight, uses of rheology in commercial practice. D.P.D.

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## Section G

## GENERAL

**141. Symposium on plasticity in building science. (Symposium su la plasticità nella scienza delle contrusioni.)** A. BERIO *et al.*, *Bologna*, 1956 (Nicola Zanichelli (Editore)). Contents include : Variational theorems of elasto-plasto-viscous equilibrium of solids (Berio). On the characteristics of Von Mises' equations of a perfectly plastic body (H. Geiringer). Approximate solutions of some problems in steady creep (P. G. Hodge, jr. and B. Venkatraman). Plastic non-homogeneity : Theory and applications (W. Olszak). Shakedown in elastic, plastic media subjected to cycles of load and temperature (W. Prager). Deformation processes and rheological patterns (E. Torroja). D.P.D.

**142. Some experiments on the question of the existence of the Weissenberg effects.** S. PETER and W. NOETZEL, *Z. Physik. Chemie*, 1959, **21**, 422–431. Techn. Hochschule, Hanover, A 5 per cent solution of collodion in butyl acetate rises 2 mm to 4 mm up the rotating inner cylinder of a concentric cylinder viscometer. A smaller rise occurs when the experiment is repeated with a layer of mercury at the bottom of the apparatus ; the rise increases when the inner (rotating) cylinder is made imperfectly round. The authors conclude that the Weissenberg effect, here and elsewhere, is due to departures from states of shear flow. [German] A.S.L.

**143. Gas lubrication.** J. A. COLE, *Research, Lond.*, 1959, **12**, 348–355. University of Western Australia, Nedlands. A survey of the history and present applications of the compressed gas bearings. E.B.A.

**144. High temperature gas viscosities–II.** C. P. ELLIS and C. J. G. RAW, *J. Chem. Phys.*, 1959, **30**, 574–576. University of Natal, Pietermaritzburg, S. Africa. Using a specially constructed silica apparatus described in Part I of this series, the viscosities of the following gases were measured : Nitrogen (700°–1000°C), nitric oxide (100–1000°C), Boron trifluoride (180–500°C), silicon tetrafluoride (200–330°C) and sulphur hexafluoride (200–850°C). Results discussed in terms of intermolecular forces. E.B.A.

**145. Extreme pressure lubricants.** N. PILPEL, *Research, Lond.*, 1959, **12**, 141. Barnes, London, S.W.13. A review of recent work and description of test methods. E.B.A.

**146. Effect of electrostatic fields on the orientation of colloid particles immersed in shear flow.** S. T. DEMETRIADES, *J. Chem. Phys.*, 1958, **29**, 1054–1063. Dept. of Mechanical Eng., California Inst. of Technology, Pasadena. The orientation distribution function for rigid colloidal particles immersed in Couette flow with an electric field parallel to the velocity gradient is derived in this study. Simple streaming birefringence experiments with variable or constant electric fields can be devised to test this theory which promises to yield a new method for measuring some geometrical and physical properties of colloidal particles. Author

**147. Dough mobility and absorption.** I. HLYNKA, *Cer. Chem.*, 1959, **36**, 378–385. Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg 2, Manitoba, Canada. Farinograms by the constant-flour and constant-dough methods were obtained at varying absorptions to give a range of dough consistencies approximately 300 to 900 Brabender units and a range of absorptions (14 per cent basis) approximately 52 to 68 per cent. When dough mobility, obtained as the reciprocal of maximum farinograph consistency, was plotted against absorption (14 per cent on dry flour basis), a linear relationship was established. The relationship and the data were used as a basis of calculating the absorption equivalent to an interval of 20 B.U. Bhe factor was 0·7 per cent absorption at the 500-unit line, but varied over the range. On the analogy with free and bound water, the amount of water that functions to confer mobility to dough, and the amount that is independent of mobility, were evaluated from the intercept of the regression equation for the absorption-mobility relation. A value of 69 per cent water per 100 g. dry flour, independent of the property of mobility in dough, was of the same order as the values for bound water reported by Kosmin and Swanson. The basic rheological implications of the mobility-absorption relation are noted. H.G.M.

**148. The estimation of starch paste fluidities.** W. R. FETZER and L. C. KIRST, *Cereal Chem.*, 1959, **36**, 2, 108–127. Clinton Corn Processing Co., Clinton, Iowa, U.S.A. A new alkaline paste procedure is presented for estimating the degree of modification of both acid-modified and oxidized starches. The proposed method for Alkaline Paste Fluidity employs a new metal funnel with a stainless-steel orifice, increased concentration of alkali, standardized stirring for the pastes, and a procedure for obtaining the zero fluidity weight. The zero fluidity weight for the new funnel is 18·0 g. of starch. Two other weights of starch are used : 90·0 g. for unmodified corn starch and 54·0 g. for the highly acid-modified and highly oxidized corn starches. The three weights are multiples of 9. This has suggested a new method of nomenclature, composed of three digits, for identification of starches. The first digit is the multiplier of 9 used in the determination, and the other two digits are the fluidity : i.e., 265. It is believed that this method of assignment will simplify the reporting and understanding of fluidity data. A table of moisture-fluidity corrections for the range of 8 to 15 per cent moisture is presented which enables the

fluidity test to be started without waiting for the moisture result. Also included is a table of relative weights of modified corn starches in terms of common or unmodified corn starch which gives approximately the the same viscosity. These data are not absolute, since the properties of an aqueous paste are subject to many variables, but they are sufficiently reliable to permit many tentative formulations in commercial use. A number of other starch varieties have been evaluated by the new alkaline paste procedure. H.G.M.

**149. The application of heat in the testing of flours for cookie quality.** W. T. YAMAZAKI, *Cereal Chem.*, 1959, **36**, 59–69. Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture. Procedures are described for the modification of physiochemical testing of soft wheat flour by the application of heat, Results of the heating mixograph, heated alkaline water retention capacity, and viscograph tests indicate that straight-grade, experimentally milled flours of varieties which bake poorer sugar-snap cookies (smaller diameters) show viscosity increases earlier and at lower temperatures of the heating process. These differences were not attributable to varietal differences in rates of heat penetration or of losses in volatile ingredients. H.G.M.

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**150. Some factors affecting performance of large pivoted-pad thrust bearings.** E. C. KUHN and G. D. COOPER, *Lubric. Engng.*, 1959, **15**, 250–255. Westinghouse Electric Corp., East Pittsburg, Pa. Gives results of the measurement of the distributions of oil-film thickness, pressure and temperature in a commercial bearing. From these results, power loss, oil flow and side leakage are computed. The data are compared with the predictions of three theories. It is concluded that a more satisfactory analysis must take into account both elastic distortion of the pad and variable viscosity and density of the oil. J.F.H.

## LIST OF JOURNALS COVERED FOR RHEOLOGY ABSTRACTS

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## LIST OF JOURNALS COVERED FOR RHEOLOGY ABSTRACTS

*Research, Lond.*
*Rev. de l'Inst. franç. du pétrole*
*Rev. Mat. Constr.*
*Rev. Mod. Phys.*
*Rev. Sci. Instrum.*
*Rheol. Acta*
*Rubb. Chem. Technol.*

*Sci. Lubric.*
*Silicates Industr.*
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*S.P.E.J.*
*Svensk Pappers Tidning*

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*Text. Res. J.*
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*Trans. Faraday Soc.*
*Trans. Plast. Inst., Lond.*
*Trans. Soc. Rheol.*

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*Summaries of Papers to be read at the Spring Meeting of the British Society of Rheology, to be held in Manchester on April 7th and 8th, 1960.*

## Slip corrections to Flow Curves of Greases determined in the Plunger Viscometer

By A. D. BRAMHALL and J. F. HUTTON (Shell Petroleum Company)

For studies of grease flow in, for example, the pipes of a dispensing system, flow curves were obtained with a plunger viscometer. In this instrument grease is sheared between the surface of a long piston (or plunger) and the inner wall of a coaxial cylinder, the motion of the plunger being along the long axis of the cylinder.

It was found that the flow curves obtained for some greases depended on the width of the gap between the plunger and the cylinder. For others the flow curves were independent of the gap width. It is impossible to use flow curves that are not independent of the instrument used in their determination. Experiment showed that the gap width effect was not caused by filtration of soap from the grease during passage through the viscometer, nor by thixotropy, nor by pressure effects on viscosity.

To account for the effect it was postulated that the composition of the grease is not uniform across the gap. In particular it was supposed that layers of softer grease are formed adjacent to the viscometer walls with unmodified grease in between. The bulk of the grease slips on these layers. The thickness of the layers is regarded as depending on the size and distribution of the soap fibre aggregates in the grease. An analysis is given of the modified flow, assuming that the softer layers have a constant thickness independent of the gap width and the material in the layers obeys the Bingham equation. Experimental results agree with the analysis. It is then shown how observed flow curves can be corrected to give the flow curve of the bulk grease and independent of the viscometer used.

Arising out of this work it is possible to propose a method for the quantitative measure of grease texture. This is because the thickness of the slip layer can be calculated approximately from the viscometer data and, as pointed out above, this thickness is related to texture.

## Hydrodynamic Lubrication in Wire Drawing

G. H. TATTERSALL, B.I.S.R.A., Sheffield

(Now at Brown-Firth Research Labs., Sheffield)

It was shown by Christopherson and Naylor that hydrodynamic lubrication in wire drawing could be provided by supplying lubricant at the entry of the die at a pressure comparable with the yield stress of the wire. The necessary pressure could be conveniently generated by causing the wire to approach the die through a tube of a diameter slightly larger than the wire diameter, sealed on to the inlet side of the die. They carried

out experiments with oil as the lubricant on wires of copper and mild steel, and developed a theory which accounted for their experimental results but suffered from the defect that all their equations contained two dependent variables, $p$ the pressure developed, and $q$ the quantity of lubricant flowing.

In the present paper a theory is developed by considering all regions up to that in which the wire deforms and making the assumption that for some distance after deformation begins the lubricant pressure remains constant. Equations are obtained by means of which $p$ and $q$ are expressed in terms of independent variables. The calculated values of pressure for Christopherson and Naylor's conditions show good agreement with their experimental results but the theoretical values of lubricant flow are too high by a factor of two to three. The probable reason for this discrepancy is that breakdown of the oil under shear has been ignored.

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Experiments were carried out, with soap as lubricant, in which $p$ and $q$ were measured as a function of wire speed $u$ for a series of accurately made tubes (or nozzles) of a range of dimensions, and for about a dozen soaps of widely varying rheological properties. It is shown that there is a maximum value of both $p$ and $q$ and that this result can be explained in terms of the theory with the additional condition that the apparent viscosity of the soap is an exponential function of wire speed of the type $\mu = \mu_0 \exp(-Bu)$.

The wire speed at which the maxima occur is the same for $p$ and $q$ and appears to be independent of nozzle dimensions but dependent on soap properties. It is equal to $1/B$.

For a given soap with different nozzles the value of the maximum pressure $p_{max.}$ is proportional to $l/h^2$, where $l$ is the length of the parallel portion of the nozzle $h$ is the clearance over the wire diameter, provided the thickness of the lubricant film is small compared with $\frac{1}{2}h$. For a given soap with different nozzles $p_{max.}$ is proportional to $\mu_0/B$.

The effects of altering the reduction of area suffered by the wire, and of a change in wire, and of a change in wire properties are shown to agree with the theory.

**Lubricated sliding on viscoelastic solids : the importance of hysteresis**

By H. MINSHALL (Department of Physics, University of Cambridge)

The sliding friction of unlubricated solids is mainly due to strong adhesions occurring at the regions of real contact but part may arise from the ploughing or deformation of the softer surface by the harder. In the case of lubricated viscoelastic solids where interfacial adhesion is small and relatively large local deformations can be obtained, the friction is mainly due to deformation losses.

A study has been made of the friction of steel on a well lubricated rubber surface and it is concluded that the frictional losses in sliding, as in rolling, are essentially due to elastic hysteresis in the rubber. On

wood too, experiments indicate the importance of hysteresis as a source of sliding friction, though in this case, the interfacial adhesion cannot be neglected.

Recent American work on the lubricated sliding of steel on polymers supports these conclusions and extends the study by taking the frequency dependence of the deformation losses into account.

### Rheology of Suspensions

By F. Schulty-Grunow
(Tecknische Hochschule, Aachen, Rhein-Westphalen)

With increasing concentration, suspensions pass from the liquid to the plastic state. The flow phenomena associated with this transformation will be considered. For small concentrations a mixture effect in shear flow will be proved, both theoretically and experimentally. The question will then be considered whether, in a suspension of barytes in water, it is the viscosity of the liquid which is important as the concentration rises, or the viscosity as calculated from the Einstein formula. In a suspension of pollen in air, the effect of the pollen on the motion of the air will be investigated ; also the influence of the pollen on the resistance of a tube to the flow of air. In suspension of clay the onset of plug flow is a consequence of the transition to the plastic state, and it will be shown how the density and viscosity of the flowing layer can be determined. Finally it will be shown how, in a soap solution, the onset of plug flow depends upon separation of the liquid phase. The general flow behaviour will be illustrated experimentally. Further, the flow curves of a thixotropic suspension are critically examined. The temperature dependence of the flow curves are experimentally and theoretically investigated. The time dependence of the stress can be precisely investigated, under non-steady conditions, by measurements. In addition the dependence of the stress on the electric field strength can be experimentally proved.

### Displacement of Thixotropic Gels from the Pores of Permeable Bodies

By G. K. Jones (Fullers Earth Union Ltd.)

Practical means of decreasing the hydraulic permeability of porous rocks are becoming increasihgly important in civil engineering operations. Injection of thixotropic gels, or liquids which gel irreversibly on standing, blocks the pores and prevents passage of fluids until a critical hydrostatic pressure differential is applied : gel is then displaced from the pores and fluid flow commences. A contribution to understanding the phenomena involved has been made by injecting beds of close-packed glass spheres with bentonite suspensions of known rheological characteristics, and relating the critical break-through pressure to grain size in the bed and the relevant properties of the suspension injected into it. A preliminary study has also been made on the pressure required to force a bentonite suspension into a permeable bed and into capillaries: the Bingham-Buckingham equation is used to correlate the results obtained.

## Micro-rheology of Pigment Dispersion by " Ball-milling in Non-aqueous Media "

By Leopold Dintenfass (Taubmans' Industries Ltd., St. Peters, N.S.W., Australia)

An investigation was carried out of the surface chemistry and rheology of pigment grinding and dispersion. The effects of pigment surface characteristics, resin types, resin concentration, solvent strength, grinding aids, ball-mill size and grinding times, were studied. The surface active compounds employed included driers.

The pigment-vehicle interactions, that is, the phenomena of adsorption (" Selective polar adsorption ") and the corresponding changes in the molecular configurations and the molecular weight distributions of the medium, were related to the efficiency of grinding. The resulting mill-bases (suspensions) were classified on the basis of their equilibrium flow curves.

The three typical modes of flow, *Newtonian*, *dilatant*, and *thixotropic*, were found to be intimately related to the colloidal states of the solid and liquid phases. A strict relationship was observed to exist between the colloidal structures of the solid phase (adsorption, flocculation, agglutination, sedimentation volume, etc.), the liquid phase (coiling, aggregation, entanglement, etc.), and the respective rheological curves.

The terminology used is based on a two-word term; the first term corresponds to the rheological behaviour of the solid phase, and the second to the rheological behaviour of the liquid phase.

It is concluded that using media of suitable rheological type and, at the same time, containing polar groups corresponding to the active areas of the heterogeneous surface of pigments, it is possible to grind efficiently and to obtain dispersed pigment suspensions of great stability.

## Some outdated presuppositions as a hindrance to a young science

By G. W. Scott Blair (National Institute for Research in Dairying)

Although the aims of science are fairly clearly defined, its scope and the delimitation of its methods are not so. Many research workers, especially those who express no interest in philosophy, subconsciously hold to a set of firmly rooted metaphysical presuppositions. Although these generally favour the most fashionable and often, in fact, highly valuable procedures, they are apt to be prejudiced against original lines of approach which might prove very profitable, at least in certain special fields.

One of the earliest illustrations of this was the strong feeling aroused by the discovery of irrational numbers. Closely parallel situations have arisen with many subsequent innovations.



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In the present paper, some fundamental principles of scientific measurement are briefly outlined in the context of rheology and certain widely-held presuppositions are discussed. It is claimed that a rheological theory should not be classed as "sound" or "unsound", unless it is logically inconsistent; but should be considered as falling within a hierarchy of complexity, the "sound" principle being to select the simplest theory which fits the data within the required limits of accuracy, following Occam's principle of economy of entities.

**Explanations and models in scientific theory construction**

By R. F. J. WITHERS (Department of Biology, Middlesex Hospital Medical School, London)

This paper aims at providing a framework against which discussion of the status of certain ideas in rheology may take place. The view is put forward that science consists of a body of statements ordered in a particular way. A statement found in science may be one of four types of statement.

(a) Observation records. Singular statements about particular events in time and space.

(b) Generalisations. Universal statements generalising observation records. These can be regarded as zero level hypotheses. The immediate aim of science is to falsify them. Those which have not been falsified over a long period assume the status of Scientific Laws.

(c) Explanatory hypotheses. These are universal statements from which generalisations logically follow. They frequently involve a change of subject matter from the subject matter of generalisations, in so far as they frequently "explain" generalisations about things in terms of generalisations about the parts of those things and the relationships in which the parts stand to one another.

(d) Consequences of explanatory hypotheses. These will include the generalisations but are in the main new generalisations which lead to predictions of new fresh observations which can then be tested by experiment.

The explanatory hypotheses are described in more detail and the role of models in arriving at them are discussed. In particular, the role of a conceptual model as opposed to what has been called a mathematical model is mentioned.

**Experimental evidence on the rheology of complex alloys and its philosophical significance**

By A. GRAHAM (National Gas Turbine Establishment, Pyestock, Hants.)

The need for background research into the rheology of gas-turbine alloys poses the problem of providing systematic descriptions of the

behaviour of materials that are believed to be too complex for exact description. The accumulated experience of experiments of engineering type suggests that regularities occur, in terms of the Nutting equation, on the lines previously found by Scott-Blair for non-metals. Detailed studies have shown that, for a wide range of materials, strain is to be represented by a sum of Nutting elements in which the exponents follow a simple numerical sequence. These phenomenological results have been firmly tested for a number of heat-resistant alloys by confirming extrapolations by factors of 10 or more in time.

The implications of the results have been found difficult to accept in some quarters for reasons of a general nature in no way concerned with the experimental evidence. The method used has been regarded as mere curve fitting, and work on commercial alloys as essentially empirical, without fundamental significance. Difficulties centre around the significance of the term " fundamental ", and attention is accordingly drawn to certain scientific aspects of the term.

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The word refers in science to a basic theoretical postulate that is made by definition. An inverse relationship holds between the status of a unifying result that might provide the basis of a postulate when the result is considered from the standpoints of atomic theory and field theory. It is necessary to distinguish also the different status of a unifying result in the two distinct phases of a science, namely in the formative phase when work is towards a yet-to-be-defined postulate, and in the development phase when work is away from a fully-defined postulate. Difficulties arise from a canonisation of ideas, such as when a successful hypothesis in one context is regarded as an absolute truth applicable in any context, and then the purity of a material is regarded as a necessary condition that results on it shall be valid.

These difficulties do not arise when the quantum-mechanical philosophy is adopted that the business of exact science is to specify numerically the experimental relationships between observables. This is the philosophy of the phenomenological method.

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## Section A

## THEORETICAL

**151. A reassessment of deformation theories of plasticity.** B. BUDIANSKY, *J. Appl. Mech.*, 1959, **26**, 259–264. It is shown that deformation theories of plasticity may be used for a range of loading paths, other than proportional loading, without violation of general requirements for the physical soundness of a plasticity theory. The extent to which deviations from proportional loading are admissible on this basis is calculated quantitatively for the simple deformation theory of Nadai. Author

**152. On " plastic " waves in solids.** J. M. BOWSHER, *Can. J. Phys.*, 1959, **37**, 1017. Imperial College, London. The study of the propagation of " plastic waves " in solids has reached a stage where it is necessary to consider which direction future research should take. Part of the present paper describes apparatus which gives results capable of being interpreted with a very minimum of theory. The remainder reviews past work, with emphasis on basic phenomena. A previously overlooked factor in the propagation of " plastic " waves is discussed.

**153. Diffusion mobility as influenced by irreversible structural modifications due to plastic deformation.** S. Z. BOKSTEIN *et al.*, *C. R. Acad. Sci. USSR.*, 1958, **121**, 1015–1018. [Russian]

**154. Viscous flow round a sphere at low Reynolds numbers (<40).** V. G. JENSON, *Proc. Roy. Soc. A*, 1959, **249**, 346–366. Chemical Engineering Department, University of Birmingham.

**155. Tortuosity concepts.** N. STREET, *Aust. J. Chem.*, 1958, 607–609 (short communication). University of Illinois, Urbana. The two concepts concerning the area available for flow in the Kozeny equation and their relation to concepts of tortuosity are considered. E.R.B.

**156. The characteristic method of solution for the problem of plane plastic strain.** J. HALLING, *Engineer, Lond.*, 1959, **207**, 250–254. The velocity and stress equations of plane plastic strain are hyperbolic linear partial differential equations. It is shown how the solution to such equations may be represented by series of characteristic curves which allow the determination of the stress and velocity conditions at all points in the deforming zone. The application of the method is demonstrated by its use in the study of the direct extrusion process. The theoretical solution for this process is compared with several results obtained experimentally using model materials whose mechanical properties approximate to the hypothetical plastic rigid material assumed in the theory. Author

**157. A molecular approach to the problem of visco-elasticity.** A. H. NISSAN and H. G. HIGGINS, *Nature, Lond.*, 1959, **184**, 1477–1478. Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York. The validity of a basic hypothesis, that the mechanical properties of such materials as paper, regenerated cellulose and ice are controlled by the number of hydrogen bonds per unit volume of material and by the potential energy of these bonds, is demonstrated.

**158. Sedimentation and effective viscosity.** G. J. KYNCH, *Nature, Lond.*, 1959, **184**, 1311. Dept. of Mathematics, Manchester College of Science and Technology, Manchester 1. A set of equations has been obtained which relate the sedimentation velocity of particles falling through a liquid to the effective viscosity of a suspension of similar particles having the same density as the fluid. From the analysis it should be possible to estimate the pressure gradient in the fluid due to the falling particles.

**159. On adsorption at the oil/water interface and the calculation of electric potentials in the aqueous surface phase.—I. Neutral molecules and a simplified treatment of ions.** D. A. HAYDON and F. H. TAYLOR, *Phil. Trans., A*, 1960, **252**, 225–248. Department of Colloid Science, University of Cambridge.

**160. Intermolecular forces and properties of fluids.—I. The automatic calculation of higher virial coefficients and some values of the fourth coefficient for the Lennard-Jones potential.** S. F. BOYS and I. SHAVITT, *Proc. Roy. Soc., A*, 1960, **254**, 487–498. Department of Theoretical Chemistry, University of Cambridge.

**161. Intermolecular forces and properties of fluids.—II. A general functional representation of intermolecular potentials, and some values of second, third and fourth virial coefficients for systematically differing potentials.** S. F. BOYS and I. SHAVITT, *Proc. Roy. Soc., A*, 1960, **254**, 499–506. Department of Theoretical Chemistry, University of Cambridge.

**162. Intermolecular forces in quasi-spherical molecules.—Part 2.** J. C. MCCOUBREY and NARINDER MOHAN SINGH, *Trans. Faraday Soc.*, 1959, **55**, 1826–1830. Department of Chemical Engineering, Imperial College, London, S.W.7. The collision integrals necessary for the calculation of transport coefficients of gasses have been computed for an intermolecular potential of the form $\phi(r) = A/r^{28} - B/r^{7}$, where r is the distance between molecular centres. These integrals have been used in combination with existing second virial coefficient computations to test the suggestion that the 28 : 7-potential describes the form of the intermolecular interactions which may be considered to occur between the centres of quasi-spherical molecules such as $CF_4$, $SF_6$, $SiF_4$ or $C(CH_3)_4$. It is shown that such a potential approximation constitutes an improvement over the usual Lennard-Jones 12 : 6-potential for three of the quasi-spherical molecules, but it cannot be used to give a completely satisfactory correlation of the transport and equilibrium properties of these molecules. W.H.B.

**163. Plastic instability in tension.** P. B. MELLOR, *Engineer, Lond.*, 1960, **209**, 517–521. The condition for instability under biaxial tension is considered for materials whose strain-hardening characteristics can be fitted by the empirical equation $\bar{\sigma} = A(B + \bar{\epsilon})$ . The argument is limited to stress systems arising from the application of a single load or two equal loads. Experimental values of the instability strains for the forming of a circular blank by fluid pressure are shown to be in good agreement with the theoretical treatment by Hill. Author



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**164. Flexural problems of circular ring plates and sectorial plates.—I.** W. A. BASSALI and M. A. GORGUI, *Proc. Cambridge Phil. Soc.*, 1960, **56**, 75–95. Faculty of Science, University of Alexandria, Alexandria, Egypt. Mathematical elasticity theory. J.G.O.

**165. Adhesion of metal films to glass.** P. BENJAMIN and C. WEAVER, *Proc. Roy. Soc., A*, 1960, **254**, 177–183. Department of Natural Philosophy, The Royal College of Science and Technology, Glasgow.

**166. The viscosity and elasticity of interfaces.** D. W. CRIDDLE, *Rheology* III Ed., F. R. Eirich, Academic Press, 1960.

**167. The normal-coordinate method for polymer chains in dilute solution.** B. H. ZIMM, *Rheology* III Ed., F. R. Eirich, Academic Press, 1960.

**168. Laminar non-Newtonian flow in an annulus with porous walls.** M. N. L. NARASIMHAN, *Proc. Fifth Congr. Theor. Appl. Mech.*, 1959, **15**, University of Roorkee, India. The laminar flow of certain non-Newtonian liquids in an annulus with porous walls is discussed. When certain restrictions are applied to the radial component of flow, it is shown that it is possible to obtain an exact solution of the Navier-Stokes, equations describing the steady state flow of a non-Newtonian liquid in an annulus having porous walls. The effects of such restricted radial flows on the characteristics of the flow field have been examined. For different cross-flows, both for injection and suction at the walls, the axial velocity profiles have been examined. The cases when the profiles of the axial component of the velocity develop points of inflexion are also studied, since the occurrence of these inflexion points suggests flow instability. The cases of infinite injection and suction are also studied.

**169. Two dimensional steady flow between non-parallel plane walls under a magnetic field.** A. C. SRIVASTAVA, *Proc. Fifth Congr. Theor. Appl. Mech.*, 1959, **12**, University of Roorkee, India. Two dimensional steady flow of an incompressible viscous electrically conducting fluid between two non-parallel plane walls in presence of a magnetic field (produced by a uniform current flowing along a wire placed along the line of intersection of two planes) has been considered for small values of magnetic Reynolds number Rm. It is found that due to the magnetic field the maximum angle between the walls for which purely divergent flow is possible, is increased.

**170. Laminar non-Newtonian flow in an annulus with porous walls.** M. N. L. NARASIMHAN, *Proc. Unesco Symposium on non-linear Physical Problems*, 1959, **11**. University of Roorkee, India. This problem is a study of laminar flow of certain non-Newtonian liquids in an annulus with porous walls. When certain restrictions are applied to the radial component of flow, it is shown that it is possible to obtain an exact solution to the Navier-Stokes' equations describing the steady state flow of a non-Newtonian liquid in an annulus having porous walls. The effects of such restricted radial flows on the characteristics of the flow field have been examined. For different cross-flows, both for injection and suction at the walls, the axial velocity profiles have been examined. The cases when the profiles of the axial component of the velocity develop points of inflexion are also studied, since the occurrence of these inflexion points suggest flow instability. The cases of infinite injection and suction are also studied.

**171. Two dimensional compressible flow past a solid body placed in a stream bounded by a plane wall.** N. R. RAJAPPA, *Proc. Fifth Congr. Theor. Appl. Mech.*, 1959, **14**, University of Rookee, India. S. Goldstein and M. J. Lighthill have found the effect of compressibility on the potential flow past a symmetrical body placed in unlimited fluid or symmetrically placed in a channel, when the irrotational incompressible flow is known. This technique is used in this paper to find the effect of compressibility on the potential flow past a symmetrical body placed in a stream bounded by a plane wall. The problem is considered as the two dimensional continuous flow past a system of real and image aerofoils placed in an unbounded stream and the required flow pattern past such a system of real and image aerofoils is then deduced by suitable transformations from the flow past a system of two equal circular cylinders and this is discussed in detail in one of the sections. The velocity on the surface of the aerofoil is given in terms of integrals which are also useful for carrying out numerical calculations capable of forming the subject matter for another paper.

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## Section B

## INSTRUMENTS AND TECHNIQUES

**172. An electrically recording rotational rheometer.** H. KAMBE, *J. Japan Soc. Test Mates.*, 1959, **8**, 354–357. Tokyo University. A torque motor replaces the torsim wire. The instrument incorporates specially designed electromagnetic detector and low frequency generator to give oscillatory torque. [Japanese, English summary]

**173. On the Weissenberg (parallel plate type) rheogoniometer.** M. TAMURA, M. KURATA and T. KOTAKA, *J. Japan Soc. Test Mates.*, 1959, **8**, 335–339. Kyoto University. [Japanese, English summary]

**174. The dynamic phase contrast coaxial cylinder viscometer.** J. ARAI and I. SUZUKI, *J. Japan Soc. Test Mates.*, 1969, **8**, 358–364. Tokyo Institute of Technology. The viscometer incorporates an end-correction device to cope with difficulties associated with tests on molten polymers. [Japanese, English summary]

**175. An improvement to the oscillating plate viscometer.** E. FUKADA, S. SHIMIZU and T. OHNO, *J. Japan Soc. Test. Mates.*, 1959, **8**, 365–369. Kobayasi Institute of Physical Research, Tokyo. The width of the resonance peak, rather than its amplitude is used to measure viscosity, thus avoiding several sources of error. [Japanese, English summary]

**176. A self-recording viscometer for industrial use.** S. ONOGI, *J. Japan Soc. Test Mates.*, 1959, **8**, 345–348. Kyoto University. The change in torque exerted to the inner cylinder is converted into a potential change by a differential transformer, amplified and recorded. [Japanese, English summary]

**177. Simple method for finding the ratio of surface tension to viscosity of a liquid.** G. M. SREEKANTATH, N. RAJARAM and C. K. PONNAPPAN, *J. Sci. Instrum.*, 1959, **36**, 378–380. University College, Trivandrum,

India. The method employs an inclined capillary tube up which the liquid is drawn by means of a manometer. Results are obtained graphically, and these are reported for water, benzene, carbon tetrachloride and nitro-benzene.

**178. Modification of a cone-plate viscometer for direct recording of flow curves.** W. H. BAUER, A. P. FINKELSTEIN, C. A. LAROM and S. E. WIBERLEY, *Rev. Sci. Instrum.*, 1959, **30**, 167–169. Department of Chemistry, Rennsselaer Polytechnic Institute, Troy, New York. An automatic control system has been constructed to increase the rate of rotation of the cone of the Ferranti-Shirley cone-plate viscometer from zero to maximum value at a constant rate and then decrease the rate of rotation of the cone from maximum to zero at the same rate. This enables flow curves to be obtained automatically using an X-Y recorder. Details of the circuits are given. Flow curves of greases which are non-Newtonian and time dependent are illustrated by curves. J.O.C.

**179. Variable-shear-rate capillary viscometer for use with fluid metals.** F. A. JOHNSON, *A.E.R.E.*, 1959, R/M 232, 14 pp. (via *J. Appl. Chem.*, 1959, **9**, ii–637). A.E.R.E., Harwell, Berks. The instrument can be used up to 600°C in slurries, at various flow rates and at apparent viscosities 1–10 cP. Calibration is with liquid bismuth at 355°C; results for Reynolds' number 300–8600 are shown. Accuracy is within a few per cent. W.J.B.

**180. Loss modulus of single fibres.** V. DISCHER, *Faserforschung*, 1960, **11**, 73–84. Textile Industry Research Inst., Budapest. A new resonance-type apparatus for determining the elastic and loss moduli of single fibres subject to oscillating elongation uhder different static loads is described. Results for various textile fibres are given. [German]

**181. A mechanical tan δ meter of direct reading type.** M. YOSHINO and M. TAKAYANAGI, *J. Japan Soc. Test Mates.*, 1959, **8**, 330–334. Kyushu University, Fukuoka. [Japanese, English summary]

**182. Stabilised torque magnetometer.** W. F. ARCHENHOLD, A. C. BROWN and J. E. THOMPSON, *J. Sci. Instrum.*, 1959, **36**, 505–506. The English Electric Co. Ltd., Nelson Research Labs., Stafford. An improved torque magnetometer has been developed which enables measurements of torque to be made with high precision and under conditions of complete stability. This instrument has been used for an investigation into rotational hysteresis loss in silicon-iron, and is also capable of application to fields other than magnetism. Author

**183. Vibration amplitude meter using moiré-fringe technique.** T. W. AITCHISON, J. W. BRUCE and D. S. WINNING, *J. Sci. Instrum.*, 1959, **36**, 400–402. D.S.I.R., Mechanical Engineering Research Lab., Mechanisms, Metrology and Noise Control Committee, East Kilbride, Glasgow. The instrument described has characteristics which make it ideal for the measurement of vibration amplitudes at frequencies below 50 c/s. and for the calibration of other transducers. Also, because its frequency range extends down to zero, the instrument can be used to detect and measure small displacements. Author

**184. Optical scanning of liquid concentration in flow studies with porous media.** E. R. DEUTSCH, *Nature, Lond.*, 1960, **185**, 675–676. Imperial Oil Research Laboratory, Calgary, Alberta, Canada. A method which can be used in a theoretical study of miscible flow and other problems in (oil) reservoir physics is described. Details are given by which monochromatic light scans the intermiscible liquids contained in a vessel packed with glass beads. The intensity of the transmitted light is determined by means of a photomultiplier unit, and from it the concentration of the liquids may be deduced.

**185. Measurement of adhesion of thin films.** P. BENJAMIN and C. WEAVER, *Proc. Roy. Soc., A*, 1960, **254**, 163–176. Department of Natural Philosophy, The Royal College of Science and Technology, Glasgow.

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**186. The measurement of dimensional stability of elevated temperatures.** W. GOHL, *Kunststoffe*, 1959, **49**, 228. This paper is mainly concerned with explaining the significance of "Martens Number", "Vicat Number" and similar values as measures of thermal stability. There is a simple explanation for the fact that the Martens test which has proved so effective for thermosets has failed for thermoplastics. [German]

**187. Performance of pressure-sensitive materials.** R. MATAS and D. W. LECUYER, *Rev. Sci. Instrum.*, 1959, **30**, 750–751. Physics and Meteorology Section, Suffield Experimental Station, Ralston, Alberta, Canada. Confirms previous conclusions (*Rev. Sci. Instrum.*, 1959, **30**, 43) and additionally the gauges were temperature-dependent, the resistance decreasing exponentially with temperature, and their performance changed with age. J.O.C.

**188. Investigations into the physics of solids by ultrasonic means.** F. GATTO, *Metallurg. ital.*, 1959, **51**, 521–524.

**189. Determination of elastic moduli of sintered metal powder compacts using an ultrasonic method.** P. RAMA RAO and A. A. KRISHNAN. *J. Sci. Ind. Res.*, 1959, **18B**, 260–261. I.D.A.

**190. An instrument for measuring cutting forces during turning.** B. I. MUKHIN, *Machines & Tooling*, 1959, **30**, 25–26.

**191. An instrument of measuring drilling cutting forces.** R. A. SHMIDT and B. I. MUKHIN, *Machines & Tooling*, 1959, **30**, 26–27.

**192. A mechanical hardness tester for cubed materials.** A. W. HARTLEY, *Lab. Practice*, 1959, **8**, 223–225. Spillers Central Laboratory, Cambridge, England. The device is suitable for tests on sugar cubes, pelleted pharmaceutical tablets, cubes and pellets for animal feeding, etc. M.F.C.

**193. Microhardness tester.** *Metal Progr.*, 1959, **76**, 25F–25H. Amer. Chain and Cable Co. A shallow indentation tester with a 136° diamond pyramid indenter is described ; it is used for testing hot metals or components exposed to radioactive or nuclear contamination. I.D.A.

**194. Method for measuring long-time hardness for determining creep of materials.** Y. E. AFANAS'EV and A. I. KOLPASHNIKOV, *Zadovsk Lab.*, 1958, **24**, 627–629. [Russian]

**195. The GKN micro-hardness tester.** *Brit. Engg. Internat.*, 1959, **42**, 58. Guest Keen and Nettlefold Research Laboratory, England. A micro-hardness tester is described which enables indentations to be spaced less than 0.025 mm apart. Foils as thin as 0.013 mm thick and individual crystals or phases can be tested. I.D.A.

**196. Testing instrument with means for centreing test bodies.** *VSP* 2, 842, 960. An impact test holder and test piece are required in which the Schnadt type piece is automatically and reliably centred.

**197. Ultra high pressure for materials research.** C. M. SCHWARTZ and W. B. WILSON, *Batelle Techn. Rev.*, 1959, **8**, 3–8. Techniques are described for achieving unusual combinations of extreme pressures and high temperatures. I.D.A.

**198. Intercomparison of Farinograph absorption obtain with different instruments and bowls.** I. HLYNKA. *Cereal Chemistry*, 1960, **37**, 67–70. Board of Grain Commissioners for Canada, Winnipeg, Manitoba. A method for precise intercomparison of different farinographs is described. The technique is illustrated by data on combinations of two farinograph instruments and three mixing bowls. Linear regression equations for the mobility-absorption relation were established, using the same flour. From these data precise values for absorption were evaluated corresponding to the 500 B.U. consistency. Conversely, values of consistency corresponding to a selected value of absorption were also evaluated. H.G.M.

**199. An automatic tester for determining the degree of ripeness of viscose.** S. ONOGI, N. KOMATSO, and S. OBUCHI, *J. Japan Soc. Test. Mates.*, 1959, **8**, 340–344. The tester records automatically the change in consistency of a viscose sample during titration with ammonium chloride solution. [Japanese, English summary]

**200. On the problem of denier variation in the melt spinning of polyamides and polyesters.** V. GRÖBE and H. VERSÄUMER, *Faserforschung*, 1960, **11**, 90–91. Inst. Faserstoff-Forsch., Teltow-Seehof, Germany. In the extrusion of molten polymers through dies of circular cross-section, the diameter of the extruded filament immediately after the die is greater than the diameter of the die. It is found that this increase of diameter is much greater the longer the die and somewhat greater the greater the melt viscosity. It is not clear whether pressure or throughput was kept constant. [German]

## Section C

## METALS AND OTHER SOLIDS

**201. Some physical properties of sea ice.—I and II.** E. R. POUNDER and E. M. LITTLE, *Can. J. Phys.*, 1959, **37**, 443–473 ; 1959, **37**, 1438–1454. Dept. of Physics, McGill University, Montreal, Quebec. Amongst other properties, the permeability to water, tensile strength and shear strength of sea ice are discussed.

**202. The flow of polycrystalline metals under simple shear.—II.** E. N. DA C. ANDRADE and K. H. JOLLIFFE, *Proc. Roy. Soc., A*, 1960, **254**, 291–316. Imperial College of Science and Technology, London

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**203. Strength of a grooved stud.** D. C. HERBERT, *Nature, Lond.*, 1959, **184**, 897–898. Engineering Labs., Snowy Mountains Hydro-electric Authority, P.O. Box 332, Cooma North, N.S.W., Australia. The breaking loads of structural steel bars, which were reduced in sectional area by a circumferential groove of semi-circular cross-section, were found to be 60% greater than predicted from the tensile strength of the material. The fractured specimens showed mainly brittle failure except for narrow bands of ductile failure around the edge. The results are discussed with respect to the theories of Petersen and Orowan.

**204. The effect of deformation on the internal friction of iron measured at the carbon peak position.** F. W. C. BOSWELL, *Can. J. Phys.*, 1959, **37**, 1474–1481. Dept. of Mines and Technical Surveys, Ottawa. As a result of deformation, the internal friction increased and then decreased with time. Corrected for a background change associated with the deformation, these results followed a time law predicted for carbon segregation to dislocations. It is concluded that the amount of carbon in random solution is increased by the deformation. By analyzing the rate of decrease of internal friction in terms of strain-ageing theory, the final dislocation densities were determined. The results also indicate that in some cases the carbon put into solution by the deformation was initially present as iron carbide.

**205. Dynamic and static deformation of Armco iron.** H. P. TARDIF and P. CHOLLET, *Nature, Lond.*, 1959, **184**, 1917–1920. Canadian Armament Research and Development Establishment, Quebec. The hardness was found to be increased for both dynamically and statically prestrained specimens of armco iron, though the increase found in the dynamically deformed specimens was of a lesser extent. Results with specimens aged after deforming to different degrees confirmed that the tensile strength of iron after strain-ageing increases with the amount of prestrain. Results of compression and tensile tests over a range of temperatures on both aged and new specimens which had been prestrained dynamically or statically are also reported. These indicate that the equivalence of effects of high strain-rates and low temperatures does not apply only during deformation but also that their effects during prestraining will influence the behaviour of iron in the same direction during subsequent straining.

**206. Adsorption and oxide formation of aluminium films.** D. D. ELEY and P. R. WILKINSON, *Proc. Roy. Soc., A*, 1960, **254**, 327–342. University of Nottingham.

**207. Embrittlement of tungsten and of molybdenum.** P. J. BURDON and G. L. DAVIS, *Nature, Lond.*, 1960, **185**, 455. Mullard Radio Valve Co. Ltd., New Road, Mitcham Junction, Surrey. From bending and tensile tests it is shown that tungsten exhibited minimum brittleness, after heating at 1600°C in an atmosphere of nitrogen and hydrogen containing 0.2% ammonia. It is also reported that heating molybdenum at 1300°C in the presence of elementary nitrogen gave minimum embrittlement.

**208. The creep of single crystals of zinc in readily fusible metallic melts.** V. A. LABZIN and V. I. LICHTMAN. *C. R. Acad. Sci. USSR*, 1958, **121**, 443–445. [Russian]

**209. Dependence on temperature of elastic moduli of tin.** P. J. REDDY and S. V. SUBRAHMANYAM, *Nature, Lond.*, 1960, **185**, 29. Physics Dept., Sri Venkateswara University, Tirupati, India. Using the composite piezo-electric oscillator method in the frequency range 100–145 kc/sec., Young's and rigidity moduli for 99% pure tin specimens have been determined over the temperature range 0°–100°C. A change in the gradient of the modulus–temperature curve is attributed to stress relaxation at the grain boundaries.

**210. A co-operative study of the hardness testing of cemented carbides.** B. M. CAUGHERTY, H. T. OATMAN, and O. W. REEN. *BNF Bull.*, 1959, **39**, 423. The test blocks were WC/Co or WC/TaC/Co. I.D.A.

**211. Stress behaviour of brittle materials.** E. B. SHAND, *Bull. Amer. Ceram. Soc.*, 1959, **38**, 653–660.

**212. Elastic moduli of polycrystals in relation to the constants of mono-crystals.** R. COLOMBO, *Metallurg. ital.*, 1959, **51**, 466–467. [Italian]

**213. The effect of internal friction on the fatigue failure of cyclically deformable machine parts.** J. S. PODSTRIGACH and M. I. CHAEVSKY, *C. R. Acad. Sci. USSR*, 1958, **121**, 268–270. [Russian]

**214. The rheology of inorganic glasses.** W. A. WEYL, *Rheology* III Ed. F. R. Eirich, Academic Press, 1960.

**215. On the strength and structure of glass.** J. E. GORDON, D. M. MARSH, MARGARET E. M. PARRAT, *Proc. Roy. Soc. A*, 1959, **249**, 65–72. Tube Investments Research Laboratories, Hinxton Hall, Cambridge.

**216. Strength impairment mechanism of glass in aqueous systems.** F. J. RADD and D. H. OERTLE, *Nature, Lond.*, 1959, **184**, 976. Continental Oil Co., P.O. Drawer 1267, Ponca City, Oklahoma, U.S.A. Tension strength studies of commercial glass fibres have shown that the fibres are weakened by exposure to water and that this effect is increased by high pH solutions. These results substantiate previous empirical data in the literature, and confirm the view that the observed impairment is due to chemical solution.

**217. Micro-hardness, microstability, and stability towards static and impact bending of thermally treated glasses.** A. I. BEREZNOI. *Izvest Vysshikh Ucheb Zavedenii, Khim i Khim Tekharl*, 1959, **2**, 82–88. See *Chem. Abs.*, 1959, **53**, 15510.

**218. The scale factor and the strength of glass.** G. M. BARTENEV and L. P. TSEPKOV, *C. R. Acad. Sci. USSR*, 1958, **121**, 260–263. [Russian]

**219. The rheology of concrete.** M. REINER, *Rheology* III Ed. F. R. Eirich, Academic Press, 1960.

## Section D

## POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

**220. Dynamic mechanical properties of high polymers.** J. PRAKASH, *J. Sci. Industr. Res.*, 1959, **18A**, 404–413. Technological Laboratory, Indian Central Cotton Committee, Bombay, India. The importance of the study of the dynamic mechanical properties of high polymers, with special reference to textile materials, is emphasised, and the various methods employed in the determination of these properties have been summarised and their limitations discussed. The dependence of the dynamic Young's modulus on static strain, dynamic strain amplitude and yarn structure is indicated. Author

**221. Investigation of molecular relaxation in polymers through their dielectric behaviour.** G. P. MICHAILOV, *Makromol. Chem.*, 1960, **35**, 26–53. Inst. for high polymer compounds, USSR Academy of Sciences, Leningrad. Recently published data on the temperature- and frequency-dependence of dielectric loss and polarization in a variety of polymers are collected together and discussed in terms of the motion of side groups and the motion of segments of the whole chain. [German]

**222. Comparison of methods for determining intrinsic viscosities from non-Newtonian viscosities.** K. H. CRAM and J. C. WHITWELL, *Text. Res. J.*, 1958, **28**, 849–860.

**223. Interpretation of flow curves in terms of molecular properties.** J. SCHURZ, *J. Colloid Sci.*, 1959, **14**, 492–500. Institut fur physikalische Chemie der Universitat Graz, Austria. Earlier work of Philippoff, Meskat and the author has shown that (1) a relationship exists between the molecular weight and the inflection point in the flow curve, and (2) the shape of the flow curve reflects the polydispersity of the solute. A short account of new experimental data is given. R.B.B.

**224. The deformation of crystalline and cross-linked polymers.** I. L. HOPKINS and W. O. BAKER, *Rheology* III Ed. F. R. Eirich, Academic Press, 1960.

**225. Crystalline structure in high polymers.** C. W. HOCK, *Hercules Chemist*, 1960, **38**, 5–9. Hercules Powder Company, Wilmington, Delaware.



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**226. Elastic and inelastic properties of some isotactic polymers.** G. NATTA, M. BACCAREDDA, and E. BUTTA, *Chemica e Industria*, 1959, **41**, 737–740. [Italian]

**227. On the mechanism of cold drawing (of crystalline high polymers).** J. FURUKAWA, K. MURAMATSU, and S. OYA, *J. Japan Soc. Test Mates.*, 1959, **8**, 320–323. Kyoto University.

**228. Analysis of temperature dispersion curves of elastic modulus in crystalline high polymers.** M. TAKAYANAGI, M. YOSHINO, and Y. SAEKI, *J. Japan Soc. Test Mates.*, 1959, **8**, 308–314. Kyushu University, Fukuoka. [Japanese, English summary]

**229. On the relaxation time distribution of crystalline polymers.** A. MIYAKE, *J. Japan Soc. Test. Mates.*, 1959, **8**, 305–307. Shiyuoka University Japan. The relaxation time spectrum of the Rouse chain is examined from the viewpoint of the statistical mechanics of irreversible processes. [Japanese, English summary]

**230. Theory of viscoelasticity of crystalline polymers.** Y. CHIKAHISA, *J. Japan Soc. Test. Mates.*, 1959, **8**, 297–300. Gakushuin University, Tokyo. [Japanese, English summary]

**231. Relaxation mechanism of crystalline polymers.** T. TAKEMURA, *J. Japan Soc. Test Mates.*, 1959, **8**, 301–304. Kyushu University, Fukuoka. Relaxation time spectra of crystalline polymers are compared with those for amorphous polymers ; the major differences occur at short relaxation times. [Japanese, English summary]

**232. Stress-strain relation of crystalline polymers.** T. KAWAGUCHI, *J. Japan Soc. Test. Mates.*, 1959, **8**, 289–296. Toyo Rayon Co. Otsu, Theoretical treatment. [Japanese, English summary]

**233. Stress relaxation of polyvinyl alcohol films.** S. ONOGI, K. SASAGURI, and T. ADACHI, *J. Japan Soc. Test. Mates.*, 1959, **8**, 278–283. Kyoto University. The effects of humidity, temperature, and crystallinity were measured. [Japanese, English summary]

**234. Note on Bhatnagar, Biswas, and Gharpurey's paper concerning the temperature dependence of the viscosity of polymer solutions.** E. EIZNER, *Zhur. fiz. Khim.*, 1959, **33**, 953–954. [Russian]

**235. Long-term tests on normal polyethylene pipes.** J. H. GISORF and H. VAN GOUDOEVER, *Kunststoffe* (1959) **49**, 6, 264. Brittle fracture may be induced in polyethylene pipes by exposing them to hydrostatic and axial stresses simultaneously. Theoretical views on the acceleration of these fracture mechanisms are confirmed by experimental results. [German]

**236. Relation between viscosity of the solution and the melt viscosity of polyethylene.** J. MAJER, *Chem. prumysl*, 1959, **9**, 494–497. [Czech. English summary]

**237. Rheology of polyethylene.** O. NAKAOA, T. HIRAI, and Y. MAEDA, *J. Japan Soc. Test. Mates.*, 1959, **8**, 284–288. Hitachi Ltd., Kitatama-gun, Tokyo. Measurements were carried out on the stress relaxation dead-weight creep and two dimensional extension of polyethylene films. The latter measurements were made by hydrostatic inflation ; elongation at break was greater than in the one dimensional case. [Japanese, English summary]

**238. Analysis of the solubility behaviour of irradiated polyethylene and other polymers.** A. CHARLESBY and S. H. PINNER, *Proc. Roy. Soc. A*, 1959, **249**, 367–386. Royal Military College of Science, Shrivenham, Berks.

**239. Cross-linking and elastic properties of ethylene-propene copolymers.** G. CREPSI and M. BRUZZONE, *Chimica e Industria*, 1959, **41**, 741–748. [Italian]

**240. Viscometry of polypropylene in solution.** G. MORAGLIO and F. DANUSSO, *Ann. Chim. (Italy)*, 1959, **49**, 902–910. [Italian]

**241. Crystallisation and dielectric spectrum of poyethylene terephthalate.** S. SAITO and J. NAKAJIMA, *J. Japan Soc. Test. Mates.*, 1959, **8**, 315–319. Agency of Industrial Science and Technology, Tokyo. Dielectric measurements were carried out over the range 0.1 to $10^6$ cycles/S., and a temperature range of $-35°$ to 110°C. Two dielectric dispersions are observed, one at high temperature and low frequency and the other at low temperature and high frequency. [Japanese, English summary]

**242. On the viscoelastic properties of crystalline polymers.—II. Polytrifluorochloroethylene.** K. NAGAMATSU and T. YOSHITOMI, *J. Colloid Sci.*, 1959, **14**, 377–384. Department of Applied Science, Faculty of Engineering, Kyushu University, Fukuoka, Japan. The stress-relaxation of polytrifluorochloroethylene was measured by the torsional method in the temperature range between 6° and 80° C, under small values of strain (maximum 0.5%). It was found that Ferry's reduction method is perfectly valid for the viscoelasticity of this crystalline polymer under these experimental conditions. Although the resultant relaxation-time spectrum, extending from $10^{-3}$ to $10^{25}$ seconds, has a flat shape and high values reflecting the common features of crystalline polymers. it has a distinct maximum at about $10^{10}$ seconds.

**243. The strain-dependence of rubber visco-elasticity.—Part I. The region of moderate strain.** P. MASON, *Trans. Faraday Soc.*, 1959, **55**, 1461–1469. British Rubber Producers' Research Assoc., 48, Tewin Road, Welwyn Garden City, Herts. Dynamic Young's modulus (at a given temperature and frequency) can be described by two parameters. The modulus components for natural, butadiene-acrylonitrille and butyl rubbers were derived from measurements of the velocity and attenuation of 1 Kc/sec longitudinal waves in stretched filaments by amounts up to 100 per cent, and over a range of temperatures. The glass-transition temperatures showed changes between +3°C and −4°C for strain up to 300 per cent. W.H.B.

**244. Variation of birefringence as an expression of structure growth during heating and cooling of high-polymer fibres.—II. Polyamide fibres.** A. MÖHRING and G. DUWE, *Faserforschung*, 1960, **11**, 7–15. Inst. Faserstoff-Forsch., Teltow-Seehof, Germany. The birefringence of Perlon and other fibres at various draw ratios is measured during heating and cooling cycles. [German]

**245. Dynamic mechanical properties of concentrated solutions of poly-n-butyl methacrylate in diethyl phthalate.** P. R. SAUNDERS, D. M. STERM, S. F. KURATH, C. SAKOONKIM, and J. D. FERRY, *J. Colloid. Sci.* [1959], **19**, 222–238. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. Real and imaginary parts of complex compliance have been measured between 10 and 2400 c/s for solutions of 30–60 per cent concentration at temperatures from −49°C to +47°C. A fractionated polymer of molecular weight $3.05+10^6$ was used. Glass transition temperatures have been determined refractometrically. Monomeric friction coefficients have been calculated. R.B.B.

**246. Creep behaviour of transparent plastics at elevated temperatures.** F. L. MCCRACKIN and C. F. BERSCH, *S.P.E.J.*, 1959, **15**, 791. Plastics Section, N.B.S. Creep measurements were carried out on five transparent plastics using uni and biaxial stresses of 1000 p.s.i. and over a range of elevated temperatures. Graphs are given showing elongation against time and temperature. The effects of temperature gradients across the samples are considered. E.B.

**247. On the relation between fatigue resistance, stiffness, hysteresis and chemical stability of synthetic rubbers.** M. M. REZNIKOVSKIĬ, L. S. PRISS and M. K. KHROMOV, *Kolloidnyĭ Zh.*, 1959, **21**, 458. Institute of Scientific Research for the Tyre Industry, Moscow. An analysis has been made of the relation between the fatigue characteristics of rubbers and their other properties. It has been suggested and proved on a number of examples that rubbers with greater internal friction possess reduced fatigue life, even if tested under conditions of equal temperature and under other equal conditions. The fatigue resistance of rubbers has been shown to be the higher the higher their tensile strengths and chemical stabilities and the lower their internal frictions, the relative importance of each of these factors depending upon the test conditions, namely, conditions of loading, temperature, nature of the surrounding medium, etc. [Russian, English abstract]

**248. Deformation-resistance, high-elastic and viscous properties of rubber solutions.** A. A. TRAPEZNIKOV and T. V. ASSONOVA, *Kolloidnyĭ Zh.*, 1959, **21**, **485**. Lab. of Oleocolloids and Monolayers, Physico-Chemical Institute of the Academy of Sciences, USSR, Moscow. Stress-strain and flow curves are determined for solutions of rubber in decalin for velocity gradients ($\epsilon$) from 14 to 5000 $sec^{-1}$. The stress-strain curves are recorded with an oscillograph. The ultimate shear-strain for 4–6 per cent solutions increases linearly with $\epsilon$ up to 5000 $sec^{-1}$. The dependence of amount of elastic recoil on the total deformation, for $\epsilon$ of 143 and 1142 $sec^{-1}$ makes it possible to calculate that maximal deformations reach 770 and 1100 per cent respectively. [Russian, English abstract]

**249. The rheology of latex.** S. H. MARON and I. M. KRIEGER, *Rheology* III Ed. F. R. Eirich, Academic Press, 1960.

**250. Mechanochemical phenomena in polymers.—Part 3. Bond strength between elements of multilayer polymer products.** G. L. SIONIMSKII and G. P. DRUGOVA, *Zhur. fiz. Khim.*, 1959, **33**, 793–798. [Russian, English summary]

**251. Mechanochemical phenomena in polymers.—Part 4. Modification of raw and vulcanised rubbers.** G. L. SLONIMSKII, V. A. KARGIN, and E. V. REZTSOVA, *Zhur. fiz. Khim.*, 1959, **33**, 988–991. [Russian. English summary]

**252. Stress relaxation in elastomers by visco-elastic mechanisms.—Part I. Natural rubber at high rates of strain and low temperatures.** G. ALLEN, G. GEE, and B. E. READ, *Trans. Faraday Soc.*, 1959, **55**, 1651–1659. Department of Chemistry, The University, Manchester. The influence of rate of strain, extension ratio and temperature on the relaxation curves of 7 natural rubber compounds is reported. All compounds showed linear visco-elastic behaviour at low extension ratios and the relaxation curves showed only minor variations which could be attributed to the vulcanization recipe. The onset of visco-elasticity is attributed to effects arising mainly from chain stiffening. W.H.B.

**253. Rheological interpretation of the mechanism of crease recovery of fibres.** H. SOBUE and K. MURAKAMI. *Text. Res. J.*, **29**, 251–260. A theoretical study has been made of the visco-elastic behaviour of fibres and filaments, in an attempt to interpret the mechanism of creasing and recovery. The relationship between crease angle of fibre, temperature and creasing time is discussed theoretically and experimentally. E.B.

**254. Cellulose rayons. Distribution of degree of polymerisation.—VI. Relation between intrinsic viscosity and degree of polymerisation of cellulose nitrate.** W. G. HARLAND, *J. Textile Inst.*, 1958, **49**, T478–T492.

**255. Viscosity-temperature relationships for dilute solutions of cellulose derivatives.—II. Intrinsic viscosities of ethyl cellulose.** W. R. MOORE and A. M. BROWN, *J. Colloid Sci.*, 1959, **14**, 343–353. Polymer Research Laboratories, Department of Chemical Technology, Institute of Technology, Bradford, England. Temperature variations of intrinsic viscosities and some other viscosity parameters for ethyl cellulose fractions in representative solvents are considered in terms of some current hydrodynamic and thermodynamic treatments of the viscosities of dilute polymer solutions. The value of $[\eta]$ decreases strongly with increasing temperature, the dependence being approximately linear. The temperature coefficient of $[\eta]$ appears to be linearly related to the molecular weight of the polymer. Except in the case of chloroform, in which aggregation of polymer may occur, values of the exponent $a$ in the expression $[\eta]=KM^a$ decrease slightly with increase of temperature suggesting decreasing chain extension. Values of the Porod-Kratky persistence length $q$, the Kirkwood-Riseman effective bond length $b$, and the angle between successive bond planes in the polymer chains suggest decreasing chain stiffness as the temperature increases. The Flory treatment is applied to obtain qualitative information regarding the contributions of different factors to the negative temperature



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coefficients of $[\eta]$, suggesting that these are primarily due to decreases in the value of $(\bar{r}_o^2/M)$, where $\bar{r}_o^2$ is the mean-square unperturbed end-to-end distance of the chains and M the molecular weight. The variations of $[\eta]$ and its temperature coefficient with solvent are briefly discussed.

Author

**256. Soluble wool proteins.—I. Light scattering and viscosity in aqueous solutions.** B. S. HARRAP and E. F. WOOD, *Aust. J. Chem.*, 1958, **4**, 581–591, Biochemistry Unit, Wool Textile Research Laboratories, C.S.I.R.O., Melbourne. S-carboxymethylkerateine 2 (SCMK2) and -keratose, two proteins derived from wool, have been characterized by nitrogen content, ultraviolet absorption, refractive index increment, light scattering, and intrinsic viscosity. Variations in the physical properties of different batches are attributed to different degrees of aggregation during the preparation. The relative viscosity decreased with time and was generally accompanied by an increase in turbidity, indicating aggregation. The effect of heating was to accelerate the fall in viscosity and increase in turbidity. Light scattering investigations showed that dissociation occurred on dilution and in some cases this could be detected by viscosity measurements. The molecular weight of several millions for SCMK2 at pH 6.7 was reduced to less than 1 million by removal of large aggregates by high-speed centrifuging, with an increase in both dissymetry and intrinsic viscosity.

Author

**257. Soluble wool proteins.—II. Light scattering and viscosity in formic acid and dichloroacetic acid solutions.** B. S. HARRAP and E. F. WOODS, *Aust. J. Chem.*, 1958, **4**, 592–606. Biochemistry Unit, Wool Textile Research Laboratories C.S.I.R.O., Melbourne. The light scattering and viscosity behaviour of S-carboxymethylkerateine 2 (SCMK2) and -keratose have been investigated in formic and dichloroacetic acids. The viscosity at 25°C of formic acid solutions of SCMK2 and -keratose showed a large decrease with time over a period of 4 weeks. On the other hand, no parallel changes in light scattering were observed and no conclusive evidence for peptide or hydrolysis could be found. Time effects in dichloroacetic acid were negligible. SCMK2, but not -keratose, behaved as a polyelectrolyte in formic acid, the reduced viscosity increasing at low concentrations an effect which was eliminated by the addition of salt.

**258. The initiation of styrene polymerisation by phenyl titanium triisopropoxide and titanous triisopropoxide.** A. M. NORTH, *Proc. Roy. Soc., A*, 1960, **254**, 408–424. Department of Physical and Inorganic Chemistry, University of Liverpool.

**259. Comparison of the molecular weights of deoxyribonucleic acids as determined from light scattering and from sedimentation and viscosity.** J. A. V. BUTLER, D. I. R. LAURENCE, A. B. ROBINS, and K. V. SHOOTER, *Proc. Roy. Soc. A*, 1959, **250**, 1–21. Chester Beatty Research Institute (Institute of Cancer Research), Royal Cancer Hospital, Fulham Road, London, S.W.3.

## Section E

## PASTES AND SUSPENSIONS

**260. Shear degradation of deoxyribonucleic acid.** LIEBE F. CAVALIERI and BARBARA H. ROSENBERG, *J. Amer. Chem. Soc.*, 1959, **81**, 5136–5139. Division of Nucleoprotein Chemistry, Sloan-Kettering Division, Cornell University Medical College, New York. Solutions of DNA were sheared ($10^3$ sec$^{-1}$) by passage through a glass atomizer. Fragmentation resulting from double chain scission was shown by studies of light scattering, sedimentation and viscosity. W.H.B.

**261. Sedimentation, viscosity and light scattering studies of bovine fibrinogen at various ionic strengths.** R. SOWINSKI, L. OHARENKO, and V. L. KOENIG, *J. Amer. Chem. Soc.*, 1959, **81**, 6193–6198. Dept. Biochemistry, Northwestern University Medical School, Chicago 11, Illinois. With increasing ionic strength of solutions containing bovine fibrinogen (2 different preparations) the sedimentation constants at infinite dilution converged to a single value for each preparation, the intrinsic viscosity increased, while the partial specific volume changes were insignificant. Molecular weights were estimated from viscosity and from light scattering. W.H.B.

**262. Particle motions in sheared suspensions. IX. Spin and deformation of threadlike particles.** O. L. FORGACS and S. G. MASON. *J. Colloid Sci.*, 1959, **14**, 457–472. Department of Chemistry, McGill University, Montreal, Canada. The axial spin of slightly curved but rigid cylindrical particles rotating in a velocity gradient have been shown to be in good accord with Jeffery's theoretical equation for ellipsoids of revolution provided that the equivalent ellipsoidal axis ratio is substituted for the true axis ratio in the equation. A theory of deformation of cylindrical particles rotating in a velocity gradient is presented. Equations are developed to calculate the critical value of (gradient × viscosity) at which the shear-induced axial compression causes the particle to buckle. Experiments conducted with Dacron, Nylon, and rayon filaments cut to various axis ratios and dispersed in various liquid media showed reasonably good agreement with the theory. Some observations of the increase of particle deformation beyond the critical gradient for bending are presented.

**263. Particle motions in sheared suspensions.—X. Orbits of flexible threadlike particles.** O. L. FORGACS and S. G. MASON. *J. Colloid Sci.*, 1959, **14**, 473–491. Department of Chemistry, McGill University, Montreal, Canada. The behaviour of deformable thread-like filaments in suspensions subjected to velocity gradients has been studied. Flexibility of the filaments was increased by swelling in suitable liquids. For a given value of (shear rate) × (viscosity of suspension) a critical length was observed at which the filament will bend. As the filament length was increased the particles formed rotating helices or coils. The work is of interest in connection with the viscosity and stressing birefringence of solutions of macromolecules. It also forms the basis of a method for measuring the flexibility of wood-pulp fibres. R.B.B.



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**264. Blood flow through narrow tubes.** R. H. HAYNES, *Nature, Lond.*, 1960, **185**, 679–681. Committee on Biophysics, University of Chicago, Chicago 37, Illinois, U.S.A. Previously reported pressure-flow curves for human blood in glass tubes of radii 50–750 $\mu$ at 25.5°C are discussed. The curves which converge on the origin, approach linearity at moderate flow rates and these linear segments on extrapolation converge to a common " nodal " point on the negative flow axis. All the curves may be represented by equations of the form

$$\dot{Q} = MP - B\,(1 - e^{-kP})$$

where $\dot{Q}$ is the volume rate of flow and $P$ the pressure gradient. The consistency curves derived from the flow data were similar in shape to the pressure-flow curves and became linear at shear stresses above 20 dynes/cm. An interpretation of these results is outlined. Also the results and the absence of a yield value, it is suggested, contradict the conclusions of Copley, Reiner and Scott Blair who have proposed that the rheological properties of blood can be described in terms of Casson's theory for varnish and ink.

**265. Changes in the structural-mechanical and rheological properties of starch gels as a result of the action of acid.** A. V. SENAKHOV and F. I. SADOV, *Kolloidnyĭ Zh.*, 1959, **21**, 692. Moscow Textile Institute. A study has been made of the changes in the structuro-mechanical and rheological properties of starch gels in the process of hydrolysis of the starch. The presence of non-thixotropic bonds in starch gels leads to the formation of a framework superimposing on the thixotropic structural lattice and responsible for the friability of the structure in general. A decrease in the number of non-thixotropic bonds in the process of hydrolysis makes the formation of a friable framework impossible at a certain stage and the gels begin to manifest plastic properties. A general equation has been derived for the change in structuro-mechanical characteristics of starch gels in the process of hydrolysis, including the basic parameters of the process of acid hydrolysis and describing the effect of the conditions of hydrolysis on the mechnical properties of a " secondary " structure forming in starch gel at a certain stage of hydrolysis. The transition from initial to hydrolyzed starch gels is accompanied by corresponding changes in their structuro-mechanical model and in the type of the rheological curve. [Russian. English abstract]

**266. On the rheology of bitumens and their flow in tubes at high temperatures.** B. V. VEDENEEV and N. V. MIKAĬLOV, *Kolloidnyĭ Zh.*, 1959, **21**, 398. Gorkovskiĭ Structural Engineering Institute, Moscow. Flow curves are given over a range of 160°–200°C and the transition between Newtonian and non-Newtonian flow is followed. A number of curves of the Ostwald " Laminarast " type are shown. It is claimed that " the fundamental hydraulic relationships for the laminar flow of heated bitumens in circular pipes have been established " and that " a scientific grounding has been laid for the process of bitumen transport in conduits with the aid of pumps from the bitumen melting vat to the place of utilization ". [Russian. English abstract] G.W.S.B.

**267. Investigations on the structural-mechanical and rheological properties of aqueous solutions of untreated thickening agents.** A. V. SENAKHOV

and F. I. SADOV, *Kolloidnyĭ Zh.*, 1959, **21**, 476. Moscow Textile Institute. Materials used for thickening printing colours in the textile industry are found to follow the same rather complex rheological model, the values of the individual parameters differing for different materials. The model consists essentially of a Burgers body attached in series to a non-cylindridal dashpot in which, as the piston is withdrawn, the viscous resistance falls. Yet thixotropy is regarded as an essential property of suitable thickening agents, a conclusion which does not appear strictly to conform to the model. [Russian. English abstract] G.W.S.B.

**268. Emulsion thickenings—possibilities in textile printing.** T. L. DAWSON, *J. Soc. Dy. Col.*, 1959, **75**, 8, 413. Dyehouse Dept., I.C.I. Dyestuffs Division, Manchester 9. The rheological properties of emulsion thickenings are compared with those of some conventional thickenings and the practical implications are discussed. E.B.

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**269. Fundamental factors determining coating colour viscosities—a progress report.** U. F. MATTSON and J. R. LEIGHTON. *TAPPI*, 1959, **42**, 1–5. Laboratory coating colours were prepared by using portions of K.C.S. clay slips. Pastes with solids contents between 8–30 per cent were made and solids content, high shear viscosities and densities measured. The fact that Robinson's equation is applicable to simple starch—clay coating colours containing 50–60 per cent solids and 12–20 per cent. starch implies they are suspensions whose specific viscosities are directly proportional to the volume concentration of pigment and inversely proportional to the volume of free liquid which in turn is related to the packed sediment volume of the dispersed pigment. E.B.

**270. Viscosity of suspensions of electrically charged particles and solutions of polymeric electrolytes.** B. E. CONWAY and A. DOBRY-DUCLAUX, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**271. Investigations on boundary friction and adhesion with the aim of investigating the interaction of highly dispersed particles. 2. The influence of cations on the adhesion of quartz disks.** G. I. FUKS and N. I. KAVERINA, *Kolloidnyĭ Zhurnal*, 1959, **21**, 718. Institute of Scientific Research for the Clock Industry, Moscow. Experiments, with the help of models, on adhesion of parallel disks in electrolyte solutions. Factors studied include : concentration, valency and radius of cations, temperature, duration and pressure of contact of disks. Results are interpreted in terms of interatomic repulsive and attractive forces. [Russian. English abstract] G.W.S.B.

**272. Stability of emulsions of water in oil.—I. The correlation between electrokinetic potential and stability.** W. ALBERS and J. TH. G. OVERBEEK, *J. Colloid Sci.*, 1959, **14**, 501–509. Van't Hoff Laboratory, University of Utrecht, Netherlands. Experiments on W/O emulsions of moderate concentration, stabilized with oil-soluble, ionizing stabilizers, show that in these emulsions no correlation exists between stability against flocculation and electrokinetic potential. Although, according to theoretical calculations, energy barriers of over 15 kT are present, if the radius of the dispersed globules is about 1 $\mu$ and the electrokinetic potential exceeds 25 mv., they apparently do not prevent lasting contact between particles.

All our emulsions flocculate rapidly, even in the presence of a surface potential considerably higher than 25 mv. A rather pronounced anti-correlation exists between the zeta potential and coalescence. It is explained as a consequence of the free mobility of the stabilizing molecules in the interface. The good stabilization against coalescence caused by some oleates of polyvalent metals is due to the formation of a thick film of partial hydrolyzates in the interface. Author

**273. Stability of emulsions of water in oil.—II. Charge as a factor of stabilization against flocculation.** W. ALBERS and J. TH. G. OVERBEEK, *J. Colloid Sci.*, 1959, **14**, 510–518. Van't Hoff Laboratory, University of Utrecht, Netherlands. It is shown by theoretical calculations that the energy barrier between charged droplets in water-in-oil emulsions is strongly diminished when the concentration of the emulsion is not extremely low. This is a consequence of the great extension of the diffuse electrical double layer in oil. The high concentration in the sediment (or cream) therefore strongly promotes flocculation. Gravity also promotes flocculation directly in all but the most dilute W/O emulsions because the weight of the particles in higher layers transmitted by the extended double layers presses on those in the lower layers and forces them together. Author

**274. Atomic approach to the rheology of sand-water and of clay-water mixtures.** W. A. WEYL and W. C. ORMSBY, *Rheology* III Ed. F. R. Eirich, Academic Press, 1960.

**275. Rheology af pastes and paints.** RUTH N. WELTMANN, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**276. Rheology of macromolecular materials.—IV. Polyvinyl chloride pastes. ii. effects of temperature.** Z. CSÜROS, M. GROSZMANN, I. GÉCZY, and K. JUHÁSZ, *Acta chim. Hung.*, 1959, **19**, 65–73 via *J. Appl. Chem.*, 1959, **9**, ii–629). The rheology of dialkyl phthalate-plasticised polyvihyl chloride pastes, in which the alkyl is methyl to octyle and the component ratio 2 : 3 to 3 : 2 is studied, using a Höppler rheoviscometer in the range 20°–60°C. A plot of viscosity vs. temperature gives a curve with a minimum identifiable as the swelling point, i.e., the temperature at which component interaction commences. [German] J.L.P.

**277. Mechanisms by which air-entraining agents affect viscosities and bleeding properties of cement pastes.** G. M. BRUERE, *Aust. J. Appl. Sci.*, 1958, **9**, 349–59. Division of Industrial Chemistry, C.S.I.R.O., Melbourne. Measurements were made of the effects of a series of surface-active agents on viscosities, bleeding rates, and bleeding capacities of cement pastes both in the absence of entrained air and in the presence of varying amounts of entrained air. The results show that the factors affecting the viscosities of cement pastes containing air-entraining agents are the effect of the agent on the adhesion of air bubbles to cement grains, the effect of the agent on the interparticle attraction between cement grains, and the presence of air bubbles themselves. The factors affecting bleeding rates and capacities of cement pastes containing air-entraining agents are the effect of the agent on degree of flocculation of cement grains and the

presence of air bubbles. It is concluded that both the adsorption characteristics of the agent on cement and the air bubbles produced by the agent have important influences on the properties of fresh air-entrained concrete. Author

**278. The rheology of printing inks.** A. C. ZETTLEMOYER and R. R. MYERS, *Rheology*, III ed. F. R. Eirich, Academic Press, 1960.

**279. A study in thixotropy of concentrated pigment suspensions.—Part I. Equilibria states.** L. O. Intenfass, *Kolloid. Z.*, 1959, **163**, 48–68. Taubmans' Industries Ltd., St. Peters, N.S.W. Australia. The thixotropy and viscosity of concentrated pigment suspensions in Newtonian liquids, such as toluene, paraffin oil, glycerin, etc., were investigated using a rotational viscometer. The sedimentation volume of pigment suspensions and the degree of flocculation of the pigment were found to be the main parameters, the others being liquids viscosity, temperature, and the viscosity of suspension above the critical rate of shear. The thixotropic effect was related to the " slope " of the rheological curve plotted on the log-log graph as kinematic viscosity against the rate of shear. The slope increases with an increase in sedimentation volume, $F$, and with an increase in the degree of flocculation, $\beta$, the latter being measured as a ratio of the sedimentation volume of the investigated suspension, to the sedimentation volume of suspension of the same pigment composition, but at absolute pigment dispersion. An increase of pigment concentration caused a marked " crowding effect ", which increased exponentially, and at very high pigment concentrations overshadowed the structural viscosity. The slope, $S$, is influenced by this " crowding effect " and as well by a " compression effect ", the latter being observed in all cases when pigment free volume (sedimentation volume) was higher than unity. An increase of temperature influences the suspension viscosity by a double action : firstly, by a decrease of liquids viscosity, and secondly, by the increase of thixotropy. Depending on the components values, suspension viscosity may increase or decrease with an increase in temperature. The effect of an increasing rate of shear is associated with two factors : firstly, with the shearing-off lyospheres, secondly, with the mechanically induced non-equilibrium dispersion of pigment particles.

**280. The viscosity of sodium humate solutions from coal.** N. RAJALAKSHMI, S. R. SIVARAJAN, and R. D. VOLD, *J. Colloid Sci.*, 1959, **14**, 419–429. Department of Inorganic and Physical Chemistry, Indian Institute of Science, Bangalore 3, India. Preparations of sodium humate made by different extractive procedures all showed a similar dependence of reduced viscosity on concentration and on added salt despite the fact that lignins were present in some preparations and absent in others. The results obtained are characteristic of the behaviour of flexible polyelectrolytes, and suggest that the sodium humate molecule or aggregate must have many single bonds in its structure so as to permit the indicated configurational changes. In the case of the purest sodium humate studied the apparent degree of dissociation is only about 50 per cent. Author

**281. Viscometric study of n-butyl titanate polymers.** A. WATANABE, K. SHIOZAWA, F. YAGURA, and T. SATO, *J. Chem. Soc. Japan, Ind. Chem. Sect.*, 1959, **62**, 1078–1081. [Japanese. English summary]

**282. Note on the intrinsic viscosity of polystyrene in mixed solvents.** J. F. HENDERSON and C. A. WINKLER, *Can. J. Chem.*, 1959, **37**, 1225–1227. Physical Chemistry Laboratory, McGill University, Montreal, Quebec.

## Section F

## LIQUIDS

**283. The splitting of thin liquid films. Kinematics.** R. R. MYERS, J. C. MILLER, and A. C. ZETTLEMOYER, *J. Colloid Sci.*, 1959, **14**, 287–299. Lehigh University, Bethlehem, Pa. The kinematics of film splitting have been explored inside a roll nip using a disc and cone apparatus especially developed for the purpose. High-speed photographs and cinematographs have been made of the action in the nip. Two regimes of flow have been discerned. At slow speeds, fluids have time to flow counter to the roll direction into the region of low pressure where separation begins. At high speeds, cavitation or bubble formation occurs in the low-pressure region. The number of bubbles formed has been counted as a function of speed, nip pressure, and film thickness : they increase with increases in the first and third of these variables, and decrease slightly with increase in the second. Pigmentation increases the number of bubbles formed. These cavitation studies have shed light on the mechanisms of film splitting and fluid transfer. Author

**284. Variation of dielectric relaxation time with viscosity.** D. V. G. L. NARASIMHA RAO, *Trans. Faraday Soc.*, 1959, **55**, 1324–1328. Physics Dept., Andhra University, Waltair, India. A systematic study of the variation of dielectric relaxation time with viscosity was made for two aromatic ring compounds—benzyl chloride and o-chlorotoluene—and three aliphatic chain molecules—n-butylamine, n-hexylamine and n-decylamine—in solution in benzene containing varying amounts of medicinal paraffin. The results are discussed in the light of the Debye equations. W.H.B.

**285. Influence of temperature upon viscosity of sodium alginate.** F. HASAHARA and Y. KUROIWA, *J. Chem. Soc. Japan, Ind. Chem. Sec.*, 1959, **62**, 851–854. [Japanese. English summary] A54–A55.

**286. Rheology of lubrication and lubricants.** A. BONDI, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**287. On the calculation of the velocity of sound in sea water.** CHARLOTTE FROESE, *Can. J. Phys.*, 1959, **37**, 775–777. Dept. of Mathematics, University of Bristol, Columbia, Vancouver, B.C.

**288. The vetrasonic flow meter.** *S.I.R.A. Technical News*, 1959, **61**, 58–59.

**289. Correlating Hercules, Hagan and Brookfield viscometers for a Newtonian fluid.** R. C. CHASE, *TAPPI*, 1959, **42**, 97–104.

**290. Principles of viscosity determination.** O. ELLEFSON, *Schr. Ver. Zellchem.*, 1958, **27**, 155–167.

**291. The thermodynamic properties of liquid helium.** R. W. HILL and O. V. LOUNASMAA, *Phil. Trans.*, *A*, 1960, **252**, 357–395. Clarendon Laboratory, University of Oxford.

## Section G

## GENERAL

**292. Cavity formation in simple pipes due to rupture of the water column.** B. B. SHARP, *Nature, Lond.*, 1960, **185**, 302–303. Civil Engineering Dept., Univ. of Melbourne, Victoria, Australia. This phenomenon is believed to occur in the pipe when the algebraic sum of the direct and reflected pressure waves tends to a value less than the vapour pressure, and this theory has been confirmed by observation. Further work is in progress.

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**293. Speeding up the calculation of results (with particular application to flowmeter analyses).** A. T. J. HAYWARD, *Lab. Practice*, 1959, **8**, 395–400. National Engineering Laboratory, East Kilbride, Glasgow.

**294. Standardisation of variable area flow meter scaling.** *Instrum. Prac.*, 1959, **13**, 618–620.

**295. Standardising fuel flow rates.** *Instrum. Prac.*, 1959, **13**, 1047–1048.

**296. Talking Paints.—I. Measurement of viscosity.** *Cellon Bull.*, 1959, **4**, 2.

**297. The principles of rheometry.** S. OKA, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**298. Rheology of spinning.** B. R. ROBERTS, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**299. Theory of screw extruders.** W. L. GORE and JAMES M. MCKELVEY, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**300. The rheology of adhesion.** J. J. BIKERMAN, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**301. Rheology in molding.** C. E. BEYER and R. S. SPENCER, *Rheology* III ed., F. R. Eirich, Academic Press, 1960.

**302. The influence of gamma radiation on the quality of several types of flour.** M. BLINC, *Brot und Gebäck*, 1959, **13**, 205–209. Extremely weak flours milled from three Italian wheats sown and harvested in Yugoslavia were subjected to gamma radiation and the improvement in quality after irradiation was followed from several points of view. The three flours Autonomia, San Pastore and Fortunato received from a Co 60 source 30,000, 50,000 and 100,000 rep. Organoleptic tests on bread and the determination of some physical properties of crumb, dough and of bread

yield showed that the irradiation of 30,000 rep. was most suitable for Autonomia and of 50,000 rep. for San Pastore and Fortunato. The Farinogram showed after an irradiation of 50,000 rep. that the degree of softening of Autonomia had decreased from 120 to 80. The Amylograms of San Pastore showed improved characteristics with all irradiated samples whereby the best curves occurred at 50,000 rep. Typical of the influence of radiation was the change in Fortunato which was regarded as particularly weak. Experiments with the Farinograph and Amylograph showed that the sample having received 30,000 rep. moved to first place. Extensograms with this sample also showed the greatest improvement at that level. In view of the results obtained there is no question that all three flours were greatly improved by the irradiation at the level of 30,000–50,000 rep. [German] H.G.M.

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**303. How hard is soft ?** *Prod. Engg.*, 1959, **30**, 14. A hardness tester is described which measures penetration and elastic recovery. I.D.A.

**304. Tests hardness: will travel.** *Product Engg.*, 1959, **30**, 14. The tester weighs only 9 oz. complete with case.

## Book review

**The Scientific Papers of Sir Geoffrey Ingram Taylor, volume II.** *Edited by* G. K. BATCHELOR. Cambridge University Press, 1960. 515 pp. 75*s*.

The second of four volumes and the first of three to be devoted to Sir GEOFFREY TAYLOR's work on the mechanics of fluids, appears under the secondary title *Meteorology, Oceanography and Turbulent Flow*. Forty-five papers, arranged in chronological order from 1915 to 1958, include among others, Sir Geoffrey's well-known series of papers of 1935–6 on the statistical theory of turbulence, and those of 1936 on the onset of turbulence in flow between coaxial cylinders, where an important distinction is drawn between rotation of the inner, and of the outer, cylinder. The reader of this volume can follow how our understanding of turbulent flow has grown, stage by stage, during the last half century and is reminded of the number of essential steps in the evolution of ideas that have been first expressed by this one distinguished applied mathematician.

The papers here collected together give a detailed picture of the development of eddying motion in the lower atmosphere, its dependence on wind velocity and surface conditions and the function of eddies in the transport of heat, momentum, vorticity and other diffusible properties and in the dissipation of sound. They discuss oscillations of the atmosphere, whether or not in convective equilibrium, the modes of instability of a stratified atmosphere, the significance of eddy size, the production of smaller eddies from larger ones and their eventual decay due to the action of viscosity in regions of concentrated vorticity, and finally the integrating concept of a spectrum of turbulence. Other subjects range from the dispersion of matter by turbulent flow in a pipe to the formation of fog and mist and the height to which a smoke plume from a source of heat should rise in

a still atmosphere. In addition to waves and tides in the atmosphere, tidal movements in the oceans are discussed, with special reference to the practically important cases of the tides in the Bristol Channel and in the Irish Sea.

The exposition is always a model of lucidity. Mathematical ideas are never put forward without a statement of the observations on real fluids, the atmosphere or the oceans, on which they might throw light ; and whenever possible the theoretical predictions which follow are compared with the results of ingenious experiments designed to check them. The merits and demerits of alternative theories are put objectively and it is clear at the end of each paper just how much has been explained. In short, the volume will be valuable, not only to the specialist as a collection of some of the most significant papers on turbulent flow theory, but also as an example and an inspiration to all applied mathematicians working in related, or in unrelated, fields.

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## Section A

## THEORETICAL

**305. The hydrodynamic effect between approaching surfaces with interposed viscous fluid films, and its influence on surface deformations.** L. H. BUTLER, *J. Inst. Petrol.*, 1960, **46**, 63–73. University College, Cardiff. The pressure distributions in the fluid film between rigid surfaces approaching at constant velocity are calculated. Various surface profiles are assumed and allowance is made for variation of fluid viscosity with pressure. The implications in the case of flat and parallel approaching faces are discussed at some length, since they demonstrate clearly the marked influence of the pressure-viscosity dependence. Whilst the problem is of interest in its own right, the discussion is extended to show that fluid films may be established in continuous metal deformation processes. It is suggested that the presence of such films may lead to the surface deterioration of the deformed metal sometimes observed experimentally. In the appendix a further extension is considered in which the deforming surface is receding with a velocity varying across its profile. The pressure distribution in such a case supports the previous hypothesis of the establishment of a full fluid film. Author

**306. A derivation of the basic equations of hydrodynamic lubrication with a fluid having constant properties.** H. G. ELROD, *Quart. Appl. Maths.*, 1960, **17**, 349–359. Department of Mechanical Engineering, Columbia University, U.S.A. Small parameter techniques are used to derive Reynolds' lubrication equations, and refinements thereof, from the full Navier-Stokes equations. An effort has been made to retain rigour in the development comparable to that used in present-day boundary-layer developments. Author

**307. Theory of the parallel plate viscometer.** A. N. GENT, *Brit. J. Appl. Physics*, 1960, **11**, 85. British Rubber Producers' Research Association, Welwyn Garden City, Herts. The theory for the rate of approach of two parallel circular plates separated by a viscous body assumes that the separation of the plates is small compared with the test-piece radius. This theory is extended to test-pieces of any thickness and is shown to be in accord with measurements on a sample of pitch. G.M.J.

**308. Dynamics of the turbulent free jet.** P. D. SUNAVALA, *J. Sci. Industr. Res.*, 1960, **19B**, 35–45. Dept. of Fuel Technology, Indian Institute of Technology, Bombay. A general free jet equation has been derived from compressible fluid flow theory which, in conjunction with data on thrust measurements, enables the axial decay curve for any jet operating at any nozzle pressure and existing temperature to be deduced. A new technique of measuring burner thrusts based on the rotating fountain principle has been devised. Author

**309. Pulsatile flow through tapered distensible vessels, reflections and the Hosie phenomenon.** R. L. EVANS, *Nature, Lond.*, 1960, **186**, 290–291. Medical School, University of Minnesota, Minneapolis, U.S.A. The effect of vessel taper on pulsatile flows of liquid through distensible tubes is presented for flows in which viscosity effects are negligible. The theory should be applicable to the flow of blood in the larger arteries of

mammals. The theory indicates that pulses can give rise to a reflected wave where the taper has a discontinuity, but not where the taper varies continuously. W.G.C.

**310. The Cauchy problem for elastic waves in an anisotropic medium.** G. F. D. DUFF, *Phil. Trans.*, 1960, **A252,** 249–273. University of Toronto.

**311. Elastomer behaviour.—I. Rupture elongation.** L. C. CASE, *Makromol. Chemie*, 1960, **37**, 243–250. Purdue University, Lafayette, Indiana. A theoretical treatment is given which leads to qualitative results relating the extensibility of a rubberlike solid to the degree and functionality of cross-linking. A.S.L.

**312. The rheological behaviour of hydrogen-bonded solids.** A. H. NISSAN, *Trans. Farad. Soc.*, 1959, **55**, 2048–2053. Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A. Assuming a normal distribution of hydrogen bond energies in cellulose and ignoring covalent and ionic bonds, the rupture energy is derived theoretically in terms of the number of bonds per $cm^3$, the length of the specimen and the mean bond energy. The theory is applied to tensile data for paper. W.H.B.

**313. Derivation of hydrodynamic equations for the quantum systems of diatomic molecules.** R. ZELAZNY, *Phys. Rev.*, 1960, **117**, 1–11. Institute of Theoretical Physics, Warsaw University, Poland.

**314. Aspects of the theories of dislocation mobility and internal friction.** J. LOTHE, *Phys. Rev.*, 1960, **117**, 704–708. Institute of Physics, University of Oslo, Norway.

**315. The relation between the flow of non-Newtonian fluids and turbulent Newtonian fluids.** R. S. RIVLIN, *Quart. Appl. Maths.*, 1960, **17**, 447. Brown University, U.S.A. A correction to the last paragraph of the paper appearing under this title in the same journal (1957, Vol. **15**, 212–215).

## Section B

## INSTRUMENTS AND TECHNIQUES

**316. Measurement of viscosity during processing [of shellac-oil varnish].** V. S. GUPTA, *Paint Manuf.*, 1960, **30**, 124. Observation of the electric current taken by a synchronous stirrer motor is used as a check on viscosity increase during varnish making. R.J.C.

**317. A simple rotatory dynamic testing machine.** A. N. GENT, *Brit. J. Appl. Phys.*, 1960, **11**, 165. British Rubber Producers' Research Association, Welwyn Garden City, Herts. A test-machine for determining the dynamic shear modulus and damping factor of rubbers imposes a simple



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shear deformation in a continuously rotated direction. Energy is dissipated even though the elastically-stored energy is apparently held constant. G.M.J.

**318. Determination of the elastic moduli of tin single crystals, and their variation with temperature.** D. G. HOUSE and E. V. VERNON, *Brit. J. Appl. Phys.*, 1960, **11**, 254. University of Southampton. An apparatus for the measurement of longitudinal and torsional resonance frequencies of cylindrical rods by electrostatic excitation is described. By this means the elastic constants of tin were determined between $-180^{\circ}$C and $+195^{\circ}$C. G.M.J.

**319. Production and tensile testing of strain-free metal specimens.** G. GREETHAM and A. J. MARTIN, *J. Sci. Instrum.*, 1960, **37**, 160–162. A.W.R.E., Aldermaston, Berks. Details are given of equipment which has been used to prepare and mechanically test single crystal specimens of beryllium from zone refined rod. An electrolytic etching machine is described whereby the test-pieces may be prepared without mechanical deformation, and details are given of a modified Polanyi apparatus in which specimens may be tested in tension at temperatures up to about 600°C. Author

**320. Grips for tensile tests on very extensible tapes.** A. G. DAY, *J. Sci. Instrum.*, 1960, **37**, 181–182. The British Electrical and Allied Industries R.A., Leatherhead, Surrey. These grips have been designed to minimise the restriction imposed by the clamped ends on the reduction in width of the specimens on extension.

**321. Measurement of cyclic strain.** T. M. DOWELL and J. A. MACKINNON, *J. Sci. Instrum.*, 1960, **37**, 138–140. National Engineering Laboratory, East Kilbride, Glasgow. The paper describes a versatile multi-way instrument for measuring periodic strain gauge signals. The strain is either shown on a meter or can be accurately measured on an oscilloscope in terms of resistance change. Full scale deflection of the meter is obtained for strains in the order of $\pm 10^{-4}$. Author

**322. Apparatus for the measurement of Young's modulus, between $-200^{\circ}$ and $+700^{\circ}$C, by transverse vibration in vacuum.** H. J. STOKES, *J. Sci. Instrum.*, 1960, **37**, 117–120. Research Dept., I.C.I. Ltd., Metals Division, Birmingham. The construction and use of apparatus for the determination of Young's modulus by means of transverse vibrations of specimens in strip form four inches long is described. Two vacuum chambers are employed, one for immersion in liquid nitrogen and the other incorporating a small furnace for operation at temperatures up to 700°C; the electronic units being common to both. Author

**323. Extensometer for semi-rigid materials.** C. D. KINLOCH and N. E. WATERS, *J. Sci. Instrum.*, 1960, **37**, 93–95. British Rubber Producers' R.A., Welwyn Garden City, Herts. A differential capacitance extensometer is described which is capable of measuring extensions between

1 and 50 per cent on an unstrained gauge length of one inch. With this instrument, complete tensile stress-strain curves to the point of rupture of the test piece may be obtained on semi-rigid materials. Author

**324. Apparatus for the measurement of the mechanical properties of fibres.** F. R. MORGAN, *J. Sci. Instrum.*, 1960, **37**, 25–27. British Leather Manufacturers' R.A., Egham, Surrey. An apparatus is described for simultaneously determining the mechanical properties of eight (collagen) fibres. The apparatus provides for tests to be made at different relative humidities, for chainomatic loading up to about 450 g. and for measurement of extensions of the order of $10^{-3}$ cm. Author

**325. Oscillator measuring equipment for vibrating-wire gauges.** W. H. WARD and J. E. CHENEY, *J. Sci. Instrum.*, 1960, **37**, 88–92. Building Research Station, Garston, Watford, Herts. The design, construction, calibration and use of a new instrument which measures the frequency of vibrating-wire gauges is presented. It utilises a variable-frequency (250–2500 c/s) electronic oscillator, which is continuously checked against a tuning-fork and regularly checked by time signals. With this instrument there is no difficulty in measuring strains to an accuracy of $10^{-6}$ during a period of several months or, with care, of $10^{-7}$ over shorter periods. The advantages of this apparatus are considered to be very favourable, and successful use in a number of adverse conditions is cited. W.G.C.

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**326. Piston ring friction—rig measurements with low viscosity oils.** A. DE FARO BARROS and A. DYSON, *J. Inst. Petrol.*, 1960, **46**, 1–18. University of Oporto, Portugal. The friction between a stationary piston with ring and a reciprocating cyclinder has been measured in a rig, in which air at a constant pressure could be admitted above the piston. The effect of oil viscosity and composition, and of rig speed and air pressure, on the friction at various points in the cycle has been studied, and conditions for the maintenance of a hydrodynamic film between ring and cylinder have been established. It appears that these conditions are most stringent during that part of the cycle corresponding to the first 30 per cent of the piston down-stroke of a normal engine, i.e. when the operating conditions are most severe. Author

**327. N.L.G.I. tentative method for matching lubricating grease flow properties with lubricating grease dispensing pump delivery.** R. D. SKOGLUND, *N.L.G.I. Spokesman*, 1960, **24**, 49–54. Texaco, Inc. A method is given by which the delivery characteristics of an air operated grease dispensing pump system can be predicted from the apparent viscosity data of the given grease. A.D.B.

## Section C

## METALS AND OTHER SOLIDS

**328. Time-dependent tensile strength of solids.** C. C. HSIAO, *Nature, Lond.*, 1960, **186**, 535–537. Univ. of Minnesota, Minneapolis, Minnesota, U.S.A. For any given value of strain, the stress obtained at different

rates of strain is linearly related with the logarithm of the strain-rate for a number of polymeric and metallic solids. This finding, together with other experimentally similar results, is discussed. It is considered that in describing the time-dependent tensile strength properties of a large number of solids there exists a basic linear law between the logarithm of the strain-rate and the applied tensile stress. W.G.C.

**329. Microcracks and the static and dynamic elastic constants of annealed and heavily cold-worked metals.** J. R. BRISTOW, *Brit. J. Appl. Phys.*, 1960, **11**, 81. Welsh College of Advanced Technology, Cardiff. The observed change in density and electrical resistivity when metals are cold-worked may be explained by sub-microscopic cracks. It is shown that such microcracks should produce relative changes in the elastic constants greater even than those in electrical resistivity. Dynamic and static measurements on annealed and cold-worked aluminium, copper and nickel showed that no changes in moduli occurred which could be ascribed to microcracks. Inexplicably large differences were observed between the static and dynamic bulk moduli and Poisson's ratios.
G.M.J.

**330. The thermal expansion anomaly of gadolinium.** R. R. BIRSS, *Proc. Roy. Soc.*, 1960, **A255**, 398–406. Imperial College, London. The thermal expansion of polycrystalline gadolinium has been measured from 80 to 750° K. The anomaly in the expansivity in the region of the ferromagnetic Curie point corresponds to an isotropic volume strain of $2{\cdot}7\times10^{-3}$. The connexion of the thermal expansion anomaly with the magnetostriction constants and the (hexagonal) magneto-elastic coupling constants is discussed. Author

**331. A contribution to the structure of coals from X-ray diffraction studies.** L. CARTZ and P. B. HIRSCH, *Phil. Trans.*, 1960, **A252**, 557–605. Crystallographic Laboratory, Cavendish Laboratory, Cambridge.

**332. Electrical properties of crystal compounds of graphite. I. Conductance of graphite bromine.** L. C. F. BLACKMAN, J. F. MATHEWS and A. R. UBBELOHDE, *Proc. Roy. Soc.*, 1960, **A256**, 15–27. Department of Chemical Engineering, Imperial College of Science and Technology, London, S.W.7.

**333. High-temperature creep of graphite.** D. B. FISCHBACH, *Nature, Lond.*, 1960, **186**, 795–797. Jet Propulsion Lab., California Institute of Technology, Pasadena, California. The creep equation proposed by Davidson and Losty (Rheology Abstracts, 1958, **1**(2), Abstract No. 235) for graphites in the temperature range 1300–2000°C is found to be applicable to graphite creep at higher temperatures, up to 3000°C. There are appreciable differences in the relation of creep to temperature and stress in the two temperature ranges. The amount of recoverable strain ranged from one-tenth to one-third of the total creep elongation, and this is discussed. W.G.C.

**334. The anisotropic thermoelectric power of graphite.** L. C. F. BLACKMAN, P. H. DUNDAS and A. R. UBBELOHDE, *Proc. Roy. Soc.*, 1960,

**A255**, 293–306. Department of Chemical Engineering, Imperial College of Science and Technology, London, S.W.7. In order to characterize the anisotropy, measurements of thermoelectric power at ordinary temperatures have been made as a function of direction on various specimens of graphite. These included commercial polycrystalline graphite partly oriented during its manufacture, compacts of small near-ideal crystal flakes oriented by compression, well-oriented pyrolytic graphite, and natural graphite with good columnar orientation parallel to the a-axis.
Author

## Section D

## POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

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**335. The infrared dichroism of a stretched polymer. I. The theoretical treatment of rubberlike polymers.** H. J. MARRINAN, *J. Polym. Sci.*, 1959, **39**, 461–468. British Rayon Research Association, Wythenshawe, Manchester. An expression is derived for the infrared dichroism of a chain of randomly jointed links representing the molecules of a rubber-like polymer under strain. The treatment is more general than previous ones and shows that infrared dichroism should provide information on molecular flexibility similar to that obtained from measurements of the stress-optical coefficient. E.H.A.

**336. Relation between the flow of polymeric substances in a parallel plate compression rheometer and in an extrusion rheometer.** KATSUHIKO ITO, *J. Polym. Sci.*, 1959, **40**, 133–147. Division of Engineering, Brown University, Providence, Rhode Island, U.S.A. The coefficient of apparent viscosity of a cellulose acetate derivative was measured as a function of shear rate in a parallel-plate compression theometer and an extrusion rheometer. At the low rates of shear obtained in the former no structural effects are found but under the high shear rates of extrusion the apparent viscosity decreases. The parallel-plate value of the viscosity coefficient corresponds to that for zero rate of extrusion in the extrusion rheometer. The intrinsic flow energy for a polymer can be obtained from the parallel-plate experiments. E.H.A.

**337. The viscosities of concentrated polymer solutions. I. Moderately concentrated solutions.** NISHIO HIRAI, *J. Polym. Science*, 1959, **39**, 435–443. Faculty of Science, Okayama University, Okayama City, Japan. The effect of intermolecular linkages on the viscosity of moderately concentrated polymer solutions are discussed. In this range the viscosity $\eta$ and the associated activation heat $Q_\eta$ are unique functions of the reduced concentration $V_R$. The following equation is derived

$$Q_\eta - Q_{\eta 0} = 2\Delta E V_R/(1+V_R)^{\frac{1}{2}}$$

where $\Delta E$ is the energy to form on intermolecular linkage. The dependence of $\eta$ on $V_R$ is also discussed. The theory is compared with experimental results. E.H.A.

**338. The viscosities of concentrated polymer solutions. II. Extremely concentrated solutions.** NISHIO HIRAI, *J. Polym. Sci.*, 1959, **40**, 255–262. Faculty of Science, Okayama University, Okayama City, Japan. The great increases of viscosity $\eta$ and the associated activation heat $Q_\eta$ in concentrated polymer solutions are attributed to two different factors. One is the formation of inter-molecular linkages and the other is the increase in glass transition temperature $T_g$ with increasing concentration. The contributions of these two factors in highly concentrated solutions are discussed quantitatively and the theory is compared with experimental results. E.H.A.

**339. Intrinsic viscosity by high shear rate determination : Polyisobutylene solutions.** E. W. MERRILL, *J. Polym. Sci.*, 1959, **38**, 539. Dept. of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Mass., U.S.A. Using a coaxial-cylinder viscometer and shear rates up to $10^{-5}$ s.$^{-1}$, observations have been made on the ultimate Newtonian viscosity of polyisobutylene solutions. At high shear rates the specific viscosity derived from these results rises linearly with concentration, and the intrinsic viscosity similarly derived appears to be independent of the solvent. Possible molecular configurations are proposed to account for the observations. E.H.A.

**340. The spreading of liquids on polyethylene film. The effect of pre-printing treatments.** A. J. G. ALLAN, *J. Polym. Sci.*, 1959, **38**, 297–306. Polychemicals Dept. E. I. du Pont de Nemours & Co., Wilmington, Delaware, U.S.A. The wettability of thin films of polyethylene has been studied by observing the equilibrium advancing contact angle of a drop of liquid on the surface. Exposure of the surface to a methane-oxygen flame increases its polarity as measured by the contact angle, and the surface tensions (of water-ethyl alcohol solutions) required to give complete spreading were determined for a series of such surfaces. These results were related to the adhesion of a polar printing ink and it was found that for good adhesion, complete wetting of the surface by the ink was necessary. E.H.A.

**341. Melt viscosity of polyethylenes : shear dependence of viscosity.** L. MARKER, R. EARLY and S. L. AGGARWAL, *J. Polym. Sci.*, 1959, **38**, 381–392. Central Research Dept., Olin Mathieson Chemical Corp., New Haven, Connecticut, U.S.A. A melt-index apparatus was adapted for use as a simple rheometer affording shear stresses in the range $10^4$ to $10^6$ dynes/cm$^2$. The fluidity of polyethylene is shown to be a linear function of the shear stress within this range. To explain the effect of temperature on the viscous flow of these materials two activation energies (corresponding to the shear-dependent and shear-independent components of the viscosity) are required. E.H.A.

**342. Theoretical consideration of the effect of crystallinity on the visco-elastic properties of polyethylene.** TETUO TAKEMURA, *J. Polym. Sci.*, 1959, **38**, 471–478. Dept. of Applied Science, Faculty of Engineering, Kyushu University, Fukuoka, Japan. A modification of Ferry's reduction principle for visco-elastic properties is proposed to account for the

presence of crystallinity in a polymer. The modification is based on a mechanical model of the semi-crystalline polymer and gives satisfactory results when applied to stress-relaxation data on polyethylene. E.H.A.

**343. Orientation of isotactic polypropylene filament and its new crystalline structure produced by high stretching.** HIROSHI SOBUE and YONEHO TABATA, *J. Polym. Sci.*, 1959, **39**, 427–433. Dept. of Applied Chemistry, Faculty of Engineering, University of Tokyo, Tokyo, Japan. Stretched filaments of isotactic polypropylene were examined by X-ray diffraction. Complete orientation of the crystallites is achieved at extension ratios of 4 to 5. Preferential orientation of the 010 plane along the fibre axis predominates at low extensions being complete at 100 per cent stretch. Further stretching of the completely oriented filament gives rise to a new metastable crystal structure having a nearly hexagonal projection in the plane perpendicular to the fibre axis. E.H.A.

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**344. Intrinsic viscosity and molecular weight of polyethylene terephthalate.** N. G. GAYLORD and S. ROSENBAUM, *J. Polym. Sci.*, 1959, **39**, 545–547. Polytechnic Institute of Brooklyn, 333 Jay St., Brooklyn I, New York. The intrinsic-viscosity/molecular weight relationship for polyethylene terephthalate is obtained by a method of end-group titration coupled with normal intrinsic viscosity measurement. The results are compared with similar, previously published data. E.H.A.

**345. A study of sedimentation equilibrium and viscosity of the system polystyrene and cyclohexane near the Flory temperature.** H. FUJITA, A. M. LINKLATER and J. W. WILLIAMS, *J. Amer. Chem. Soc.*, 1960, **82**, 379–386. The Department of Chemistry, University of Wisconsin. For the system polystyrene and cyclohexane osmotic pressure, light scattering and viscosity data are given. From the theory of Kurata, *et al.*, it is possible to predict the temperature dependence of the second virial coefficient of a given solution in a range of temperature from measurements of intrinsic viscosity at corresponding temperatures. W.H.B.

**346. Existence of a sharply defined maximum relaxation time for monodisperse polystyrene.** A. V. TOBOLSKY and K. MURAKAMI, *J. Polym. Sci.* 1959, **40**, 443. Frick Chemical Laboratory, Princeton University, Princeton, New Jersey, U.S.A. The master stress-relaxation curves of amorphous polymers have hitherto been resolvable only by approximate methods and into a continuous distribution of relaxation times. A new procedure is now proposed by which, in favourable cases, the master curve for stress-relaxation modulus in the rubbery flow region can be resolved into a discrete distribution of relaxation times including a well defined maximum relaxation time. The procedure gives reasonably well defined values for the two highest relaxation times when applied to monodisperse and polydisperse polystyrenes. E.H.A.

**347. Viscosity of concentrated methacrylic acid-styrene copolymer solutions.** YUS. S. LIPATOV and P. L. ZUBOV, *Vysokomol. Soedineniya*, 1959, **1**, 1655–1658.

**348. The flow properties of branched macromolecules.** K. E. DELMANN, *Faserforschung*, 1960, **11**, 107–113. Inst. Faserstoff-Forschung, Teltow-Seehof, Germany. Viscosity data for solutions of polystyrene in toluene, benzene, and tetralin, and of branched and unbranched polyacrylonitrile in dimethylformamide indicate that the points of inflexion on flow curves for a given system at different concentrations fall on a line whose inclination to the axes is a measure of the degree of branching. It is not shown, however, that the results are independent of the length and diameter of the capillary viscometer used. [German] A.S.L.

**349. Note on the molecular weight dependence of blending effects on the stress-relaxation behaviour of polyvinyl acetate film.** KAZUMIKO NINOMIYA and MICHITARO SAKAMOTO, *J. Phys. Chem.*, 1960, **64**, 181. Phys. Chem. Lab., Dept. of Fisheries, Kyoto Univ., Maizuru, Japan. The relation between the stress relaxation modulus of a blend of fractions of differing molecular weights and the stress relaxation moduli of the separate fractions is investigated experimentally. [Letter] D.W.S.

**350. The relation between intrinsic viscosity and molecular weight for partially alcoholized polyvinyl acetates.** A. BERESNIEWICZ, *J. Polym. Sci.*, 1959, **39**, 63–76. Electrochemicals Dept., E. I. du Pont de Nemours & Co., Niagara Falls, New York, U.S.A. Viscosities of partially alcoholized polyvinyl acetates were measured using water as solvent. Whilst the Huggins constant increases with increasing proportion of non-alcoholized acetate groups, the intrinsic viscosity $[\eta]$ decreases, reaching a minimum at about 87 per cent alcoholysis. A relation is established between $[\eta]$, the degree of alcoholysis and the molecular weight of the polymer. E.H.A.

**351. Molecular weight dependence of intrinsic viscosity, diffusion constant and second vivial coefficient of polyacrylonitrile.** HIDEHIKO KOBAYASHI, *J. Polym. Sci.*, 1959, **39**, 369–388. Research Dept., Asahi Chemical Industry Co., Nobeoka, Japan. Intrinsic viscosity and diffusion constant were measured on nine fractions of polyacrylonitrile of molecular weights from 28,000 to 575,000. Quantitative relations were obtained between molecular weight and, respectively, intrinsic viscosity, diffusion constant and second vivial coefficient. An explanation is offered for the difference between the viscosity equation obtained and similar equations in the literature as well as for the discrepancies in those previous results. E.H.A.

**352. An entropy stress study of various textile fibres.** S. L. DART, *Text. Res. J.*, 1960, **30**, 372. Claremont Men's College, Claremont, California, U.S.A. A stress-strain study has been made of various fibres to determine their entropy force behaviour at room temperature. The relative importance of the entropy and internal energy forces is shown with some illustrations of the use of these quantities in understanding the fine structure of polymers. Details are presented to show the effects of extension and godet stretch on some samples. Author

**353. Compressional behaviour of textile fibres.** S. BACKER, *Text. Res. J.*, 1960, **30**, 405. Textile Division, Massachusetts Institute of Technology, Cambridge 39, Mass., U.S.A. A brief report on an experimental investigation of the unidirectional compression behaviour of filaments of nylon and polyethylene. D.W.S.

**354. Compressional behaviour of textile fibres.** J. B. MILES, *Text. Res. J.*, 1960, **30**, 408. Chemstrand Research Center, Decatur, Alabama, U.S.A. A brief report on an experimental investigation of the unidirectional compression behaviour of drawn nylon bristle. D.W.S.

**355. Mechanical properties of cotton yarns parchmentised with sulphuric acid.** A. G. CHITALE, S. V. GOKHALE and P. C. MEHTA, *J. Sci. Industr. Res.*, 1960, **19A**, 138–144. Ahmedabad Textile Industry's Research Association, Ahmedabad, India. Breaking strength and elongation have been measured on single cotton yarns treated with sulphuric acid of parchmentizing strength for different periods, and the effects of temperature, addition of formaldehyde, and premercerization of yarn have been investigated. The elongation at break is reduced by increased duration of treatment, and an increase in temperature of treatment causes a decrease in strength. Addition of formaldehyde retards the action of sulphuric acid permitting treatment of yarns for much longer periods. Author

**356. Structural properties of cotton fibres : Part 1—convolution angle and its relation to tensile strength.** S. M. BETRABET, K. P. R. PILLAI and R. L. N. IYENGAR, *J. Sci. Industr. Res.*, 1960, **19A**, 91–94. Technological Lab. Indian Central Cotton Committee, Bombay. High correlation between tensile strength and convolution angle of 22 Indian cottons has been observed ; a good correlation has also been observed between X-ray angle and convolution angle for 13 cottons. Irrespective of the species, it has been found that Indian cottons fall in line with the correlation of strength and convolution angle which is not in accordance with MEREDITH's finding. Author

**357. A rheological interpretation of the Hottenroth Index method for viscose.** SHIGEHARU ONOGI and KOSHIKI HAYASHI, *Text. Res. J.*, 1959, **29**, 873. Department of Textile Chemistry, Kyoto University, Kyoto, Japan. A concentric cylinder type of viscometer is described which gives a continuous record of the change of viscosity of a given solution during titration with a second liquid. The instrument has been used to investigate the rheological properties of viscose solutions during titration with various salt solutions, notably ammonium chloride. It is concluded that the method of determining the " ripeness " of a viscose solution by measuring its Hottenroth index depends upon the thixotropic nature of the viscose-ammonium chloride mixture. D.W.S.

**358. Stress relaxation and the transition temperature of wool.** B. J. RIGBY, *Text. Res. J.*, 1959, **29**, 926. C.S.I.R.O., Wool Research Laboratories, Ryde, N.S.W., Australia. The stress-relaxation behaviour of a number of chemically and physically modified wool fibres has been

examined and shown to correlate with the temperature of transition of the particular modified wool. The transition temperature has been discussed previously by FEUGHELMAN, HALY, and RIGBY. Below the transition temperature the stress decays in 1 hr. by 33 per cent and above the transitiion temperature by 73 per cent of its initial value. These quantities are independent of the particular modification and appear to be associated with reversible and non-reversible transformations of native keratin. Author

**359. On the state of aggregation of high-molecular compounds. 6. Rupture characteristics of anisotropic films of polycaprolactam.** R. I. FEL'DMAN and S. I. SOKOLOV, *Kolloidnyi Zh.*, 1960, **22**, 97. Moscow Institute of Chemical Engineering, Moscow. The ultimate extension and strength of anisotropic polycaprolactam film specimens cut out at various angles to the direction of their orientation have been determined. For the relative ultimate extension ($\epsilon_x$) and strength ($\sigma_x$) as a function of the angle between the direction of the orientation and of the stretching force the following expression has been obtained :

$$\epsilon_x = \epsilon_0 + (\epsilon_{90} - \epsilon_0)\left[1 - \sin(90^\circ - x)\right] \text{ and}$$

$$\sigma_x = \sigma_0 - (\sigma_0 - \sigma_{90}),\ \sin\ x,$$

where $\epsilon_0$, $\sigma_0$, $\epsilon_{90}$ and $\sigma_{90}$ are the relative extensions and strengths when the angle $x$ equals 0 and 90° respectively. The correlations have been interpreted from the viewpoint of the flexural fold hypothesis of crystalline polymer chains that unfold on stretching. [Russian. English abstract] Author

**360. Adhesion of high-polymers. 4. Influence of mechanical factors on the adhesion of high-polymers.** A. P. PISARENKO, A. I. SHAPOVALOVA, and S. S. VOYUTSKII, *Kolloidnyi Zh.*, 1960, **22**, 57. The All-Union Institute for Scientific Investigations for Leathercraft, Moscow. The strength of attachment of polymers with low specific adhesion increases tens and hundreds of times with increase in mechanical disruption of the surface, in its porosity and in the elementary fibres projecting from the surface of the fabric. In the presence of mechanical adhesion the bonding strength ordinarily depends upon the cohesive strength of the adhesive. [Russian. English abstract] Author

**361. The influence of fillers on the properties of polydimethylsiloxane.** A. S. NOVIKOV and F. S. TOLSTUKHINA, *Kolloidnyi Zh.*, 1960, **22**, 42. Institute of the Synthetic Rubber Industry, Moscow. The effect of silica fillers on the structure and mechanical properties of mixtures and vulcanizates on the basis of polydimethylsiloxane has been investigated. The interaction of the polymer and filler was characterized by elementary analysis of the quantity of bound rubber in the gel and by the number of effective units of the gel network. The effect of the arising structures on the mechanical properties of the polymer-filler mixture was investigated by measurement of the development and fall of creep. The structure of the vulcanizates was determined from their swelling characteristics and by the apparent equilibrium modulus of elasticity. On preparing

the mixture by mastication the silica fillers form stable polymer-filler bonds. On vulcanization, depending upon the activity of the filler an additional number of bonds appears. The mechanical properties of raw mxitures were compared with those of vulcanizates. The physical and mechanical properties of vulcanizates are the higher, the greater the deviation from Newtonian motion, the greater the capacity of the filler for structuration. [Russian. English abstract] Author

**362. The alternation of bond lengths in long conjugated molecules. II. The polyacenes.** L. SALEM and H. C. LONGUET-HIGGINS, *Proc. Roy. Soc.*, 1960, **A255**, 435–443. Department of Theoretical Chemistry, University of Cambridge.

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**363. Glass temperature of co-polymers.** E. A. DIMARZIO & J. H. GIBBS, *J. Polym. Sci.*, 1959, **40**, 121–131. American Viscose Corporation, Marcus Hook, Pennsylvania, U.S.A. A recent theory relating glass transition temperature to chain stiffness is applied to copolymer systems. A simplified treatment leads to an equation of the form of the Gordon-Taylor equation but whose coefficients have a different physical significance. The glass temperatures of a series of polyethylene adipate terephthalate co-polymers are predicted within experimental error, and the equation is also applied to the polymer system poly-$\eta$-alkyl methyl methacrylate with varying $\eta$. E.H.A.

**364. Counterion binding by polyelectrolytes. V. The effect of binding of univalent cations by polyphosphates on the intrinsic viscosity.** P. D. ROSS and U. P. STRAUSS, *J. Amer. Chem. Soc.*, 1960, **82**, 1311–1314. The School of Chemistry of Rutgers, The State University. The effect of alkali metal ions on the molecular dimensions of a long-chain polyphosphate has been determined by viscosity measurements at 0°C in aqueous solutions maintained at 0·2 ionic strength with tetramethylammonium bromide. All alkali metal ions depress the intrinsic viscosity, but in different ways. It is shown that the intrinsic viscosity is not a unique function of either the degree of ionization of the polyphosphate or the degree of binding of the alkali metal ions. W.H.B.

## Section E

## PASTES AND SUSPENSIONS

**365. Plasticity in theory and practice.** E. C. BLOOR, *Brit. Ceram. Soc. Trans.*, 1959, **58**, 429–453. Clay materials owe their plasticity to fineness, to platiness, and to crystal and surface structure as it affects water films round the plates. The effect of pH and electrolytes on charges arising from isomorphous substitution within the crystal lattice, and at fractured edges of plates, are related to changes in the type of flocculations in acid and alkaline conditions, and to such features as water retention, dry clay density, and dry strength. Anisotropy of structure produced by flow can be detected by a peel technique. The difficulties and results of

laboratory tests are considered ; the best index of plasticity appears to be the strain, not the stress at the yield point or the maximum stress. Laboratory tests, though useful for distinguishing raw materials, may fail to reveal more subtle effects that occur in production. More knowledge of the clays used, and more accurate control of the water content of bodies, are required. Alignment of particles results in unequal drying and firing shrinkages, so producing built-in stresses that cause distortion and cracking. Coloured clays show the pattern of flow which, in conjunction with contraction figures, can be used to interpret the direction of alignment of the clay particles.

**366. Rheological behaviour of clay bodies.** A. BAUDRAN and D. DEPLUS *Brit. Ceram. Soc. Trans.*, 1959, **58**, 454–469. The fundamental properties that characterize rheological behaviour are considered. A laboratory apparatus has been designed to study these properties ; tubular test pieces are deformed in torsion, and the values of deformation and of force exerted are recorded simultaneously. At any point during a test the force applied can be removed, and the value of the deformation at a given instant $t$ can be maintained constant for any period $T$. From tests made, the following conclusions can be drawn ; (i) the greater the angle of rupture of a body, the better its workability ; (ii) for shaping by extrusion, turning or hand moulding, the yield stress must be as high as possible, to avoid the deformation of pieces under their own weight or when being handled immediately after shaping. A study of different types of deformation reveals recoverable or elastic deformations which depend chiefly on the total deformation.

*Total Deformation.* These deformations are responsible for internal making-stresses ; the zones of greatest deformation are liable to cause zones of less deformation to flow when the stress due to elasticity exceeds the yield value of the body. In this way it is possible to determine the sensitivity of a body by its post-shaping deformation.

**367. The rheology of ceramic slips and bodies.** F. MOORE, *Brit. Ceram. Soc. Trans.*, 1959, **58**, 470–494. The rheological properties of ceramic slips with various additions of deflocculants have been studied at both high and low shear-rates. A mathematical model, based on the formation and destruction of " links ", is suggested to account for thixotropic behaviour. A later section deals with torsion experiments on clay cylinders, particularly with certain " memory " effects observed with alternating torques. A possible explanation, based on energy barriers, is discussed.

**368. Sedimentation and effective viscosity.** D. R. OLIVER, *Nature, Lond.*, 1960, **185**, 912–913. Chemical Engineering Department, University of Birmingham. The equation derived by Kynch (Rheology Abstracts, 1960, **3**, No. 32) for the relative settling velocity of particles having density equal to that of the dispersing liquid is compared with similar equations for particles settling in a fluid of density equal to that of the suspension as a whole. Results with suspensions having particle size ratios 1·40 : 1 and 1·03 : 1 are given as evidence of the unsatisfactory

nature of the Kynch equation, and it is suggested that the relative settling velocity is more nearly dependent on the square of the volume concentration.

**369. Sedimentation and effective viscosity.** G. J. KYNCH, *Nature, Lond.*, 1960, **185**, 913–914. Manchester College of Science and Technology, Manchester, 1. Both the equation of Kynch and the equations cited by OLIVER (see previous abstract) are not in close agreement with the experimental results. Results for "Kallodoc" spheres in water and in an alcohol-water mixture and for glass spheres in glycerol-water appear to agree equally well with both equations. The serious discrepancy found with results for equi-sized spheres requires more consideration.

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**370. Rheological properties of barytes suspensions.** A. W. EARNSHAW and J. C. SPROSON, *Nature, Lond.*, 1960, **186**, 378–379. National Coal Board Northern Division, Scientific Dept., "The Grange", Longbenton, Newcastle-upon-Tyne 12. Suspensions of barytes, containing particles of all sizes less than 250 m$\mu$, were investigated using a Ferranti portable viscometer. Over a wide range of shear-rates (68–950 s.$^{-1}$) the consistency curves showed that the suspensions were Bingham fluids. From these curves the yield point and plastic viscosity were estimated for suspensions containing different solids concentrations and containing solids over a range of fineness. The concentration at which a discontinuity occurred in the plastic viscosity-concentration curves could be linearly related to the particle size, and it is suggested that this discontinuity is related to immobile layers of liquid trapped by the surface irregularities of the particles. W.G.C.

**371. The temperature dependence of some structural and mechanical characteristics of clay pastes.** V. B. CHERNOGORENKO, *Kolloidnyi Zh.*, 1960, **22**, 101. Institute for Scientific Investigations on Building Materials and Products, Kiev. With the object of determining the optimum temperature of heating of ceramic pastes a study has been made of the temperature dependence of the conditional dynamic yield-value, of the Bingham viscosity and of the strength of the structure formed. The conditional dynamic yield-value as determined from the discharge-flow pressure curves and the strength of the structure as determined by means of a conic plastometer have been found to be independent structure-mechanical characteristics. A linear relationship has been found between the logarithm of the Bingham viscosity and the inverse absolute temperature. The casting properties of heated clay pastes are well described by the Volarovich plasticity equation. [Russian. English abstract] Author

**372. Gel development in drilling fluids.** F. W. JESSEN and CAN NACI TOKTAR, *Petrol. Engr.*, 1960, **32**, B48–B60. The University of Texas. Clay suspensions used as drilling fluids exhibit widely varying thixotropic properties. Here is an instrument that presents a possible means for determining yield point of drilling muds and measuring rate of development of gel strength. Author

**373. A study in paint vehicles. Part IV. Microrheology : theory, classifications, calculations.** L. DINTENFASS, *J. Oil Col. Chem. Ass.*, 1960, **43**, 46–53. Taubmans Industries Ltd., Mary Street, St. Peters, N.S.W., Australia. Rheological classification of paint vehicles is suggested, and the described types include Newtonian, dilatant, and thixotropic systems, and some combinations of these systems. A table of physical constants of some solvents is enclosed to facilitate calculations. W.H.B.

**374. The flow properties of emulsion paints.** F. P. GRIMSHAW and R. A. W. PATEMAN, *J. Oil Col. Chem. Ass.*, 1960, **43**, 34–43. British Oxygen Research & Development Ltd., Deer Park Road, London, S.W.19. A study of the influence of the rheological properties on the working properties. Testing methods and the influence of loss of water by evaporation and absorption by porous surfaces is discussed. W.H.B.

**375. Some observations on the rheology of carbon black suspensions.** C. C. MILL, *J. Oil Col. Chem. Ass.*, 1960, **43**, 77–95. Printing, Packaging & Allied Trades Research Association, Patra House, Randalls Road, Leatherhead, Surrey. Some experiments with suspensions of carbon black in printing ink vehicles are described. The effects of the history of the sample, shear rate and time of shear on the flow curve have been studied and it is deduced that two types of structure exist. Of these one is weak but forms rapidly, and the other rigid and slow in formation. It is concluded that the flow curve for this type of suspension cannot be described by the two-constant formulae of Bingham and Goodeve, and a better fit is obtained with a three-constant equation. W.H.B.

**376. The calculation of viscosities of alkyd solutions.** L. J. BARANYAI, *J. Oil Col. Chem. Ass.*, 1960, **43**, 214–223. 29, Campbell Avenue, Normanhurst, N.S.W., Australia. The viscosity of a solution of resin in a solvent at concentration $N$ can be calculated from a solution in another solvent at concentration $N$ given the viscosity of both solvents, and empirically determined viscosity factors for the solvents and the resin. W.H.B.

**377. Predicting grease performance from capillary viscometry data.** J. G. SAVINS, *Lubric. Engng.*, 1960, **16**, 108–109. Socony Mobil Oil Co., Dallas, Texas. W. R. MILLER *et al.* (Abstract No. 137 (1959)) showed that the apparent viscosity of lubricating greases depended on the length/diameter ratio of the capillary tube. Data for one of the greases are treated in terms of an inlet correction that is added to the nominal capillary length. Writing the correction as $nr$ where $r$ is the capillary radius, $n$ increases with shear rate and levels out at a value of about 180. In contrast $n$ is near 0·57 for Newtonian liquids. J. F. H.

**378. The properties of mixtures of plastic greases.** G. V. VINOGRADOV and V. V. SINITSYN, *Khim. i Tekjnol. Topliv i Masel*, 1960, 27–32. Results are given in the form of tables and graphs of the changes in mechanical properties as a function of the composition of the mixture. Measurements were made of viscosity at various rates of shear and temperature,

yield stress and syneresis, on binary mixtures of calcium, sodium and lithium soap greases. It is shown that the mechanical properties, particularly the yield stress, usually change irregularly with composition. [Russian] J.F.H.

**379. Thixotropic properties of greases.** K. I. KLIMOV and B. I. LEONT'EV, *Khim. i Tekhnol. Topliv i Masel*, 1960, 17–20. Describes experiments on four types of grease in which mechanical working was carried out in the annular gap of a rotational viscometer. In strictly controlled conditions the rate of shear was varied from 10 to 1840 $s.^{-1}$. The processes of breakdown and subsequent recovery of the structure were assessed by changes in yield stress. [Russian] J.F.H.

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**380. Structural-mechanical properties of solutions, gels and coagula (coacervates) of gelatine.** V. A. PCHELIN and N. YA. SOLOMCHENKO, *Kolloidnyi Zh.*, 1960, **22**, 63. The Lomonosov Institute, Faculty of Chemistry, Chair of Colloid Chemistry, Moscow. The viscosity and strain characteristics of gelatine converted to a new phase (coacervate) by the action of sodium sulfate and resorcinol have been investigated with the aid of a new type of [concentric cylinder] elasto-viscometer. The sodium sulfate coacervate preserves the structural and mechanical properties characteristic of gelatine, but differs in the possession of a higher elasticity and a higher melting temperature. The resorcinol coacervate behaves as a Newtonian fluid of considerably lower viscosity than the initial gelatine solution. It has been suggested that under the action of resorcinol a change in configuration of the gelatine macromolecules takes place caused by the formation of hydrogen and saline bonds between the former and the latter. [Russian. English abstract] Author

**381. Rheological properties of gels : viscoelasticity of mercury sulphosalicylate solution.** T. DANNO, *Bull. Chem. Soc. Japan*, 1959, **32**, 1033–1037.

**382. Effect of particle size and interfacial film on the viscosity of disperse systems.** E. S. RAJAGOPAL, *Z. Phys. Chem.*, 1960, **23**, 342–347. Indian Inst. of Science, Bangalore 12. A discussion of data and theory is given ; the importance of slip at the surface of suspended particles in relation to viscosity and sedimentation velocity is emphasized.

**383. Investigations on the dielectric and rheological properties of plastic dispersed systems.** YU. F. DEINEGA, A. V. DUMANSKII, G. V. VINOGRADOV and V. P. PAVLOV, *Kolloidnyi Zh.*, 1960, **22**, 16. Institute of General & Inorganic Chemistry, Academy of Sciences, Kiev. Dielectric properties of different greases are differently affected by deformation. Anisotropy produced by flow is partly maintained on removal of stress. Reorientation, etc. can be followed by dielectric measurements. [Russian. English abstract] G.W.S.B.

**384. Graphical integration of the Maxwell fluid equation and its application.** R. F. CROUCH and A. CAMERON, *J. Inst. Petrol.*, 1960, **46**, 119–125. Department of Mechanical Engineering, City & Guilds College, London.

Maxwell's equation for the friction of a visco-elastic fluid with viscosity varying with pressure is derived. The solution of this equation, giving the friction for the conditions met in gears (a band contact zone), is achieved graphically by the method of isoclinals. It is also extended to a circular contact zone (spheres). It is found that the friction deviates from the pure Newtonian value when the relaxation number $T$ gets beyond unity. $T$ is defined as $\left(\frac{\eta_{max}/G}{b/U}\right)$, i.e. $\frac{\text{Peak viscosity/shear modulus}}{\frac{1}{2}\text{ Hertzian width/speed}}$, which is $\left(\frac{\text{Relaxation time}}{\frac{1}{2}\text{ transit time}}\right)$. This is applied to some gear scuffing experiments of Borsoff. It is not certain whether they are in the region where visco-elasticity plays a part. Further consideration shows that while it is unlikely that the oil film formation is affected by visco-elasticity, the friction may be. Author

**385. Flow of blood through narrow tubes.** G. W. SCOTT BLAIR, *Nature, Lond.*, 1960, **186**, 708–709. National Insitute for Research in Dairying, Reading. A further communication on the implications of using Casson's equation in the study of the flow of suspensions through capillary tubes with particular reference to a paper by HAYNES (Rheology Abstracts, 1960, **3**(2), Abstract No. 264).

## Section F

## LIQUIDS

**386. The flow of fluids through capillaries, powder beds and porous media.** G. MAIDANIK, *Trans. Farad. Soc.*, 1960, **56**, 118–127. British Oxygen Research and Development Ltd., Deer Park Road, London, S.W.19. A semi-empirical theory is developed. The slip term is based on the interaction of the molecules of the fluid with the surfaces of the powder bed. This approach successfully bridges the gap between the hydrodynamic region and the diffusion region. The general features of the experimental results are accounted for. W.H.B.

**387. An index of viscosity.** A. CAMERON, *J. Inst. Petrol.*, 1960, **46**, 58–60. Department of Mechanical Engineering, City and Guilds College, London, S.W.7. The modified Vogel equation

$$\eta = k \exp.\left\{b/(t+95)\right\}$$

is described and its main characteristics considered. It is shown that for *O vi* oils the exponent $b$ is dependent only on the viscosity at a given temperature, here 100°F, and is expressed by the relation

$$b_0 = 184 + 450 \log_{10} v$$

where $v$ is the kinematic viscosity in centistokes at 100°F. If any other oil has the same viscosity at 100°F but a different value of $b$, as it will if its *vi* is not zero, then the *R*-rating is defined as

$$R = \left(\frac{b_0 - 1}{b}\right) 1000$$

this is applied to oils of 100 *vi* ; the thicker oils have a higher *R*-rating. Author

**388. Viscosity temperature characteristics of oils.** A. CAMERON, *J. Inst. Petrol.*, 1960, **46**, 56–58. Department of Mechanical Engineering, City and Guilds College, London, S.W.7. Most of the standard viscosity temperature laws require that

$$\left(-\frac{1}{\eta}\cdot\frac{d\eta}{dt}\right)$$

should be a simple function of the temperature. This is studied and found not to hold outside a limited temperature range. A much better correlation is obtained by plotting the logarithm of the derivative

$$\log\left(\frac{d\eta}{dt}\right) \text{ against } \log(\eta)$$

The significance of this for an index of viscosity is discussed. Author

**389. The viscosity of hydrocarbons at low temperatures.** P. I. SANIN, *Khim. i Tekhnol. Topliv i Masel*, 1960, 11–18. Viscosity-temperature relationships have been established for 30 hydrocarbons and hydrocarbon mixtures over the range −50 to +150°C. Hydrocarbons studied were those of the aliphatic series of both normal and branched structure, the alkyl substituted derivatives of tetralin and decalin, and other cyclic hydrocarbons. Results are shown graphically. [Russian] J.F.H.

**390. Structure and viscosity of liquids camphor+pyrene mixtures.** R. K. HIND, E. MCLAUGHLIN and A. R. UBBELOHDE. *Trans. Farad. Soc.*, 1960, **56**, 328–330. Dept. of Chemical Engineering, Imperial College of Science and Technology, London, S.W.7. Viscosities of liquid mixtures of camphor with pyrene have been determined over the whole range of compositions, at temperatures ranging between 160° and 230°C. Effects of molecular shape on viscosity and on the additivity law for mixtures are discussed. W.H.B.

**391. The effect of thickening mixtures of petroleum liquids and silicone liquids with high polymer additives.** D. S. VELIKOVSKII and L. V. CHERVOVA, *Khim. i Tekhnol. Topliv i Masel*, 1960, 30–37. Many mixtures of oils obey the Walther blending rule. In this paper mixtures that do not obey this rule are termed anomalous. The addition of polymer to oil mixtures which do not themselves exhibit a viscosity anomaly does not induce anomalous behaviour. Where the mixtures already show an anomaly, addition of polymer affects its magnitude. Solutions of polymers in mixtures of petroleum oil and silicone liquids possess a viscosity anomaly. The polymers used were : polyethyl hexyl methacrylate, vinopol (polymer of vinyl-*n*-butyl ether) and polyisobutylene, of molecular weights 8500, 4000 and 8800 respectively. [Russian] J.F.H.

**392. Viscosity–temperature relationships of pyrrole and pyrrolidine.** R. K. HIND, E. MCLAUGHLIN and A. R. UBBELOHDE, *Trans. Farad. Soc.*, 1960, **56**, 331–334. Dept. of Chemical Engineering, Imperial College of Science and Technology, London, S.W.7. Viscosities of pyrrole and pyrrolidine have been measured over a range of temperatures from their freezing points up to about 70°C. Viscosity against temperature plots indicate that for both liquids the degree of association increases gradually as the temperature is lowered. Results are discussed in relation to other structural information about these liquids. W.H.B.

**393. The viscosity of dinitrogen tetroxide and its binary mixtures in organic solvents.** C. C. ADDISON, B. C. SMITH, *J. Chem. Soc.*, 1960, 1783–1788. The University, Nottingham. Viscosity data for the pure liquid, and mixtures with cyclohexane, carbon tetrachloride, toluene, ethyl acetate, acetic anhydride in the range $-20°$ to $+20°C$. W.H.B.

**394. Diffusion across the oil/water interface.** J. T. DAVIES and J. B. WIGGILL, *Proc. Roy. Soc.*, 1960, **A255**, 277–291. Department of Chemical Engineering, Pembroke Street, Cambridge. The work is concerned with the resistance to the diffusion of a third component across an interface separating two liquids.

**395. Thermal diffusion in solutions of electrolytes.** J. N. AGAR and J. C. R. TURNER, *Proc. Roy. Soc.*, 1960, **A255**, 307–330. Department of Physical Chemistry, University of Cambridge.

**396. The effects of high dose rates of ionizing radiations on solutions of iron and cerium salts.** J. ROTBLAT and H. G. SUTTON, *Proc. Roy. Soc.*, 1960, **A255**, 490–508. Physics Department, St. Bartholomew's Hospital Medical College, London, E.C.1.

## Section G

## GENERAL

**397. The calorimetric determination of the heats of adsorption of oxygen on evaporated metal films.** D. BRENNAN, D. O. HAYWARD and B. M. W. TRAPNELL, *Proc. Roy. Soc.*, 1960, **A256**, 81–105. Department of Inorganic and Physical Chemistry, Liverpool University. A Beeck-type calorimeter has been used to measure the integral heat of adsorption of oxygen on evaporated films of titanium, chromium, manganese, iron, cobalt, nickel, niobium, molybdenum, rhodium, palladium, tantalum, tungsten, platinum and aluminium. Author

**398. On the quantitative transformation of chemical into mechanical energy with homogeneous, contractile systems.—I.** W. KUHN, G. EBNER, H. J. KUHN and D. H. WALTERS, *Helv. Chim. Acta*, 1960, **33**, 502–517. Phys. Chem. Inst., Basle University. Continuing investigations on materials which artificially simulate muscle, certain properties of cross-linked polymer gels formed from equal parts of polyacrylic acid and polyvinyl alcohol are given. In particular, certain gels when extended in the presence of water increase in cross-section, corresponding to a negative value ($-0{\cdot}36$) for Poisson's ratio. [German] A.S.L.

**399. Sorption and diffusion of simple paraffins in silica-alumina cracking catalyst.** R. M. BARRER and T. GABOR, *Proc. Roy. Soc.*, 1960, **A256**, 267–290. The Physical Chemistry Laboratories, Chemistry Department, Imperial College, London, S.W.7.

**400. The viscosity of some fluorocarbons in the vapour phase.** J. C. McCoubrey and Narinder Mohan Singh, *Trans. Farad. Soc.*, 1960, **56**, 486–489. Chemical Engineering Department, Imperial College, London, S.W.7. Measurements have been made of the temperature coefficients of viscosity of the vapours of tetrafluoro-ethylene, hexafluoro-ethane, perfluoro-n-pentane and perfluoro-n-hexane. For all of these vapours the temperature coefficients of viscosity are smaller than those for the corresponding hydrocarbons. This has been interpreted in terms of the intermolecular forces between fluorocarbon molecules which change steeply with the distance between molecular centres.

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*Summaries of some Papers read at a Symposium on The Rheology of Polymers, held by the British Society of Rheology at the University College of Swansea on September 8th, 9th and 10th, 1960.*

## On the Methods of Measuring Normal Stress Differences in Shear Flow

By A. S. LODGE (British Rayon Research Association, Manchester)

In the rectilinear shear flow of isotropic liquids, there are only four independent non-zero stress components (a shear component $p_{21}$ and three normal components $p_{11}$, $p_{22}$, $p_{33}$) when taken relative to a rectangular Cartesian coordinate system $Ox_1\,x_2\,x_3$ in which $Ox_1$ is parallel to the lines of flow and $Ox_2$ is perpendicular to the shearing planes. Following the pioneer work of WEISSENBERG[1], various methods have been tried or suggested for measuring $p_{11}$, $p_{22}$, $p_{33}$ or their differences. These methods essentially involve slow shear flows with curved lines of flow and in some cases curved shearing surfaces.

*Cone and plate.* In shear flow between a cone and plate in relative rotation, WEISSENBERG and ROBERTS[2] measure the pressure $(-p_{22})$ on the plate (or cone), the pressure $(-p_{33})$ at the free liquid surface in the gap between cone and plate, and from these calculate the values of $p_{11}$ using the stress equation of motion

$$rdp_{33}/dr = p_{11} + p_{22} - 2p_{33}, \tag{1}$$

where $r$ denotes distance from the axis of rotation.

This method is open to criticism, because the boundary conditions for stress cannot be satisfied unless the free boundary is part of a sphere, centre at the cone apex, and therefore in practice the required state of shear flow is liable to be disturbed near the free boundary where the measurements of $p_{22}$ and $p_{33}$ are made. To assess the importance of these disturbances, it is desirable to find other methods of measurement.

For a very general class of materials, $p_{22}-p_{33}$ (and $p_{11}-p_{33}$) depend only on the shear rate $G$ in the types of shear flow here considered[3]. $G$ is independent of $r$ in the cone/plate system, and it follows from (1) that

$$rdp_{22}/dr = p_{11} + p_{22} - 2p_{33}. \tag{2}$$

Hence the right-hand combination of normal pressure differences can be determined from pressure measurements on the plate at points away from the free liquid boundary. The determination of a second combination of differences is less straightforward. The total nett thrust $F$ in the cone/plate system has been used[4], but the appropriate relation

$$F = \tfrac{1}{2}\pi R^2 (p_{11} - p_{22}) \tag{3}$$

again depends for its validity on having the state of shear flow persist up to the free boundary (of radius $R$). The same difficulty is present in POLLETT's method[5] of measuring thrust on the whole plate and thrust on a part of the plate.

For materials for which $p_{11}+p_{22}-2p_{33}$ is not zero, it can be shown that (even with neglect of inertial forces) the required state of shear flow cannot (in principle) be maintained by the application of external surface forces alone[6]. Results of some recent calculations on the corresponding disturbances to be expected in practice throughout the gap between cone and plate indicate that the effects of these should usually be negligible.

*Parallel plates.* For shear flow between parallel circular plates in relative rotation, we have in place of (1), the equation

$$r dp_{22}/dr = p_{11}-p_{22} \tag{4}$$

and $G$ is proportional to $r$; hence

$$r dp_{22}/dr = p_{11}-p_{33}+Gd(p_{33}-p_{22})/dG \tag{5}$$

Again, the left hand side can be determined from measurements of the pressure on either plate. From (2) and (5), which may be regarded as simultaneous equations for $p_{11}-p_{33}$ and $p_{22}-p_{33}$, we obtain the equation

$$(G\frac{d}{dG}-1)(p_{22}-p_{33}) = (r dp_{22}/dr)_p-(r dp_{22}/dr)_c \tag{6}$$

where the suffixes $p$, $c$ denote values for parallel plates and for cone and plate. Integrating (6) and using the fact (3) that the quantities involved must be invariant with respect to a change of sign of $G$, we finally obtain the equation

$$(p_{22}-p_{33})_G = G\int_0^G \left\{(r dp_{22}/dr)_p-(r dp_{22}/dr)_c\right\}_{G'} dG'/G'^2 \tag{7}$$

which gives (in principle) a second difference of normal stress components. This possibility has been pointed out by MARKOVITZ[7] who remarks that the sensitivity of the method may be low for certain materials; in any case, the presence of the factor $G'^2$ in the denominator is unfortunate as it gives weight to the data at low values of shear rate. The method is independent of conditions near the rim of the rotating member. Some results obtained with this method are being given to the present conference by Mr. ADAMS.

KOTAKA *et al.*,[8] suggest combining pressure gradient measurements with measurements of either central pressure, or rim pressure, or total thrust (all in a parallel plate system) to obtain two differences of normal stress components, but this method again depends on having an undisturbed state of shear flow up to the rim of the rotating member.

*Concentric cylinders.* For shear flow between concentric cylinders in relative rotation we have (in place of (1) and (4)) the equation

$$r dp_{22}/dr = p_{11}-p_{22}. \tag{8}$$

In this case $-p_{22}$ is the pressure on either cylinder. If a small gap between the cylinders is used so as to give a practically uniform shear rate, the pressure difference $dp_{22}$ across the cylinders gives $p_{11}-p_{22}$ directly but, being proportional to $dr$, may be too small to measure reliably in relation to other sources of pressure difference in such a system. However, MARKOVITZ[7] has pointed out that values for $p_{11}-p_{22}$ can in fact also be obtained from the difference of pressures on the cylinders when a large gap



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is used, provided that the viscosity be known as a function of shear rate so that the shear rate at the rotating cylinder may be calculated. This appears to be a promising method of obtaining a second difference of normal stress components, but the data published[9] up to the present are hardly adequate to enable assessments of sensitivity and reliability to be made.

RIVLIN's calculations on " helical " flow have drawn attention to the possibility that (in principle) two differences of normal stress components may be obtained from the difference of pressures on the walls of a narrow-gap concentric cylinder apparatus if an axial flow of liquid arising from a uniform axial gradient of pressure be superimposed on the usual Couette flow arising from relative rotation of the cylinders. This method would have the advantage of using only a single apparatus to give both differences required, but the axial flow might in practice lead to complications when thixotropic liquids are used. Such complications can be overcome in the purely rotational instruments considered above by continuing steady rotation until steady pressure readings are obtained. No pressure measurements in helical flow have as yet been reported.

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[8]T. KOTAKA, M. KURATA and M. TAMURA, *J. Appl. Phys.*, 1959, **30**, 1705.
[9]F. J. PADDEN and T. W. DE WITT, *J. Appl. Phys.*, 1954, **25**, 1086.

## Some Aspects of the Friction of Elastomeric Plastics

By R. H. NORMAN (Research Association British Rubber Manufacturers, Shawbury, Shrewsbury, Shrops.)

This paper discusses three inter-related aspects of the sliding friction of polythene and plasticised PVC against steel. The introduction describes briefly the two current theories of friction. The first of these ascribes the friction to the shearing of junctions formed between asperities on the two surfaces, the area of these junctions being controlled either by plastic flow of the media or by elastic deformation. The second theory is that the frictional forces result from hysteresis energy losses in the media. The first of these theories is appropriate to the friction surfaces being considered in this paper except under certain conditions.

Each sample employed in the investigations was prepared in thin sheet form and two pieces (7 cm by 2·5 cm) were stuck to a metal plate and ground to remove the moulded surface. These prepared samples were tested against a ground steel plate of such area that at no point on the traverse did the sample overlap its edges. The traverse of the plate was about 9 cm and measurements were generally made after the sample had been subjected to (*a*) about 50 traverses of the plate under a load of 10 kg (1 kg for the experiments involving changes of load) and (*b*) a sufficient number of traverses under the required load and conditions of measurement to obtain equilibrium conditions. There was transfer of plastic to the steel surface in some cases and some production of wear debris in all cases although the quantity was frequently small. The measurements were made at room temperature with a sliding speed of 0·3 cm/sec.

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The first aspect of the frictional behaviour considered is the dependence of the tangential force upon the normal load. This has been examined on high and low density polythenes and on PVC containing various concentrations of di-octyl phthalate, di-butyl phthalate and various proprietary plasticisers including epoxy types. It is shown that the more rigid materials (PVC with little or no plasticiser and polythene) give a frictional force substantially proportional to the normal load, i.e. a constant coefficient of friction, over the range of normal loads from 0·07 kg to 30 kg. However, with the more highly plasticised PVC samples, considerable changes in coefficient of friction occur in this range of normal loads. The results are compared with the behaviour expected from the theories previously mentioned.

The second aspect is that of the influence upon the coefficient of friction of the debris produced by sliding. This debris takes several forms which grow from the fine filaments torn from the surface of the PVC and fragments of metal torn from the steel surface. These fine particles often aggregate to form rolls and these may further aggregate or flatten to form plate-like particles which may be either loose or embedded into the surface. In many cases the rolls act as minute roller bearings except at higher loads where the reverse effect may occur. The following experiment illustrates this point. A sample was run under a load of 30 kg until a copious supply of rolls was formed. The coefficient of friction was then determined at 0·07 kg load both before and after removal of the rolls. The experiment was repeated with various values of the lower load. The coefficient of friction after removal of the rolls was constant at 1·2 but that on the surface bearing the rolls varied from about 0·4 at 0·07 kg up to 1·4 at 10 kg. At the higher loads, the rolls are appreciably deformed and bed into the surface. This may cause sliding (with associated ploughing of the surface) to replace rolling, or may cause the rolls and the surface to deform elastically with a consequent loss of energy (and thus increased friction) by a hysteresis mechanism. The only observed effect of the plate-like particles is an increase in friction, which may in a severe case be two-fold. In the majority of tests carried out on harder samples, the friction debris does not aggregate appreciably at loads up to 30 kg, and a small quantity of debris, even if aggregated, has little effect on the coefficient of friction. On softer samples the effect may be quite serious.

The third aspect is that of contamination of the surface either by external agents, in this case coal dust and/or water, or by a surface film of exuded plasticiser. The former have little effect on the harder polymers (in some cases the coefficient of friction is actually increased) but cause a considerable reduction in the coefficient of friction of softer compounds. With water, this is probably due to the greater ease with which a film may be sustained between the two surfaces if one of then if soft. In samples which are so highly plasticised that plasticiser exudes to the surface, the coefficient of friction under pseudo static conditions may be extremely high ; in fact a moderate adhesion between the two surfaces occurs. The effect on the dynamic coefficient of friction at moderate speeds is less marked.

Some PVC surfaces have to fulfil certain functions in which they must slide readily on another surface. Most of the remainder must not slide under prescribed conditions. The above three aspects of friction must be considered in assessing whether the object will fulfil these requirements.

## Friction and Deformation of Nylon

By N. Adams (British Rayon Research Association, Manchester)

The observed dependence of friction on load for polymers is satisfactorily represented, over large load ranges, by an equation of the form $F=\alpha W^n$ where $F$ is the friction, $W$ the load and $\alpha$ and $n$ are constants ; $n$ usually has a value between $\frac{2}{3}$ and 1[1]. Because, in the special case when $n=1$, this equation reduces to $F=\mu W$. it has been regarded as a more general form of Amonton's laws of friction and has been explained by a modification of the " adhesion theory " of friction which has successfully interpreted Amonton's laws[2].

According to the adhesion theory the friction between rubbing bodies is closely related to their " true contact area ", which may be defined as the area over which they are within range of one another's molecular forces. If the surfaces of the bodies are perfectly smooth, the true contact area is equal to the " apparent contact area " which is the area bounded by the line at which the two bodies diverge. (The apparent contact area is determined by the macroscopic deformation of the bodies and is measurable). If however the surfaces are rough, contact can only occur at the tips of those asperities which lie within the apparent contact area. The true contact area is then determined by the deformation of these asperities and is consequently always smaller than the apparent contact area but approaches it as the surfaces tend to perfect smoothness and as the average pressure on the contact increases.

Where the deformation of the asperities is plastic, as is common for the asperities on metal surfaces, the true contact area is proportional to the load and Amonton's laws hold. Where the deformation of the asperities and the substrate is elastic, however, the true contact area is predicted to have a power law dependence on load similar to that observed for friction[3].

Measurements by LINCOLN[4] and PASCOE and TABOR[5], in which high average pressures were used so that approximate equality between true and apparent contact area was expected, showed that apparent contact area was related to load by a power law with an index similar to that observed in friction measurements on the same polymer. This showed that for a broad description of polymer friction it is adequate to assume a constant shear strength for the true contact area.

In the present work a method has been established for the measurement of the apparent contact area between a nylon hemisphere and a rigid (glass) plane which is free from some systematic errors of previously used methods and which can be employed during slow speed sliding. Simultaneous measurements of apparent contact area and friction on the same sliding contact, with obvious advantages, were therefore possible.

The diameter of the apprent contact area was obtained from the diameters of interference fringes (Newton's rings) near its periphery, and the original curvature of the nylon surface, by means of a theoretical expression for the " profile " (viz. the shape of a radial section perpendicular to the glass plate) of a hemisphere which is deformed elastically. The theoretical profile was verified experimentally for separations between the nylon and glass from $\sim 6\lambda$ to $\frac{1}{8}\lambda$. ($\lambda = 5461$Å) for range of specimen radii, loads and loading times.

The apparent contact area was found to be negligibly affected in shape and in size by tangential forces up to at least 0·8 times the load. This is consistent with theoretical predictions for Hookean materials.

Both friction and apparent contact area were found to have power law dependence on load but with differing indices $n$, and $m$ respectively. The value of $(n-m)$ was $+0{\cdot}073 \pm 0{\cdot}0125$ i.e. significantly greater than zero and was not appreciably affected by considerable changes of specimen curvature, sliding speed, and time of loading. This implies that the ratio Friction/Apparent contact area increases slowly with load as (Load)$^{0{\cdot}073}$, or more significantly with mean pressure $P$ on the apparent contact area, as $P^{0{\cdot}25}$, for values of P from 0·5 to 4·0 Kg/mm$^2$. This increase of Friction/Apparent contact area with pressure could be explained either by an increase in the ratio of true/apparent contact areas with pressure whilst retaining a constant shear strength of the true contact area, or by an increase of this shear strength with pressure.

Although, *a priori*, the first alternative appears more likely because physical surfaces can never be ideally smooth we conclude, from a detailed discussion of elastic asperity theories of friction, that the second must be adopted.

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## The Anisotropy of Young's Modulus of Drawn Polyethylene

By Miss G. RAUMANN (British Rayon Research Association, Manchester)

*General.* The anistropic nature of drawn polymers has been recognised for some time and the variation with direction of such properties as refractive index, light absorption, X-ray diffraction etc. have been used to study structure and molecular orientation. Relatively little work has been done however on the anistropy of the mechanical properties of such polymers. The present work is part of an investigation designed to provide a complete description of the elastic behaviour of drawn polyethylene at small strains.

It is assumed that the classical elasticity theory for anisotropic bodies can be used to describe the behaviour of drawn polymers for sufficiently small strains from the drawn condition. For a general anistropic body 21 independent elastic constants are required to characterise the material. For bodies possessing elements of symmetry this number is reduced according to the type of symmetry shown. Polymers drawn under simple tension would be expected to exhibit transverse isotropy about the direction of drawing and the number of independent elastic constants required is then five. This is to be compared with the two independent elastic constants characteristic of bodies with complete isotropy.

Three independent combinations of the five constants required for characterisation of a drawn polymer can be obtained from measurements of Young's moduli of strips whose long axes are inclined at different angles to the axis of drawing. Experiments to determine these three combinations for polyethylene drawn to various extents are described. Values of the three combinations are presented and from them and elasticity theory the ranges in which the values of the two remaining constants must lie are estimated.

*Experimental.* Isotropic sheets of low density polyethylene (Alkathene Grade 7) were drawn at room temperature to various (permanent) draw ratios ranging from 1·0 (undrawn) to 4·6 (the maximum attainable with the present material and technique). Strips about $25 \times 2 \times 0{\cdot}5$ mm were cut making angles of 0°, 45° and 90° with the drawn direction, their Young's moduli (denoted $E_0$, $E_{45}$ and $E_{90}$ respectively) were measured for cyclic-incremental strains of 0·1 per cent superimposed on steady strains up to a maximum of 2 per cent, the whole of the deformation being recoverable with time. In the strain region covered the Young's modulus was essentially independent of strain. The cyclic incremental strain was induced by a " square wave " loading cycle of period 24 seconds.

The experimental results may conveniently be divided into 3 regions of draw ratio.

(1) *Draw ratio* 1·0 *to* 1·25. All three moduli decrease with draw ratio. The decrease is greatest fror $E_0$ and least for $E_{45}$. The lowest value of $E_0$ is 60 per cent of the isotropic value. A similar minimum for $E_0$ has been reported for nylon 6·6 but does not occur in the case of cellulose, wet or dry [WILSON[1] and SHINOHARA & TANZAWA[2]].

The decrease of moduli in polyethylene is accompanied by an increase in density and birefringence and X-ray diffraction diagrams show a systematic change over the whole of the draw ratio range. The decrease in modulus does therefore not appear to be due to a decrease in crystallinity or to some special molecular orientation.

(2) *Draw ratio* 1·25 *to* 3·3. In this region the modulus in the draw direction is less than the modulus in the perpendicular plane, both increasing in value as the draw ratio increases. The two moduli become equal at draw ratio 3·3. $E_{45}$ continues to decrease over this range of draw ratios. The observation that $E_{90}$ is greater than $E_0$ below draw ratio 3·3 is contrary to expectation and contrary to the trend found in cellulose[1, 2].

(3) *Draw ratios above* 3·3. The modulus in the stretch direction increases more rapidly than $E_{90}$; the ratio $E_0/E_{90}$ increases from 1·0 at draw ratio 3·3 to 1·6 at draw ratio 4·6. $E_{45}$ continues to decrease until at the highest draw ratio it has fallen to about 40 per cent of the value of the isotropic modulus or 8 per cent of $E_0$. Thus the maximum differences in moduli are not found between the draw direction and the perpendicular plane, but between $E_0$ and $E_{45}$. No molecular interpretation of this behaviour can at present be put forward. It can be shown however, on purely phenomonological grounds that the low value of $E_{45}$ compared with $E_0$ and $E_{90}$ implies a similarly low value for the rigidity modulus for shears in planes containing the symmetry axis (e.g. torsion about the symmetry axis).

Comparison of these results with the results of WILSON[1] and SHINOHARA and TANZAWA[2] on drawn cellulose and with brief investigations we have carried out on other polymers, suggests that the pattern of results found for drawn polyethylene is not typical of drawn crystalline polymers.

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## Measurements of Pressure Gradients in cone-and-plate and in parallel plate viscometers

By N. ADAMS (British Rayon Research Association, Manchester)

A method by which two independent normal stress differences in a flowing liquid can be obtained from measurements of pressure gradients in both cone-and-plate and parallel plate viscometers is described by Dr. A. S. LODGE in an earlier paper at this conference.

Experimental application of this method requires that disturbances of the assumed laminar flow of the liquid should be minimised so that the measured pressure gradients are the consequences of the normal stresses

in the liquid. This demands considerably greater precision in the construction and the adjustment of the apparatus than is required for shear stress measurements or even for total thrust measurements. For example, axial movements of the cone cause radial flow of liquid in the gap and hence cause pressure gradients on the stationary plate which can be large if the gap angle is small and the viscosity is high[1]. Although the time average of these gradients would be near zero, because the mean position of the cone is constant, it is desirable to keep their amplitudes small by restricting the axial movement of the cone. In the present apparatus the amplitude of this movement has been reduced to $\sim 10^{-5}$ inches. The accuracy of shape of the cone and the plate are of less importance, tolerances of $\sim 10^{-4}$ inches being adequate.

Departures from perpendicularity between the rotation axis of the cone and the plane of the stationary plate lead to non-uniform shear of the solution and also to hydrodynamic forces due to diverging or converging flow. Use is made of these effects by levelling the plate until pressures at diametrically opposite points equidistant from the axis are equal and are unchanged when the direction of rotation is reversed. Given an adequate levelling mechanism the accuracy with which these pressures can be equalised is determined by the accuracy of a pressure measurement, which in our case was $\sim 5$ dyne cm$^{-2}$.

Inertial effects of the rotating liquids are kept small ($<1$ per cent of the measured pressures) by using cones with semi-vertical angles $\sim 86°$ so that only low angular velocities are required to produce the shear rates in the range 2 to 30 sec$^{-1}$ which were used. The use of small gap angles also leads to the stability of the laminar flow because several perturbations can be shown to depend on the second or higher powers of this angle. Two perturbations, however, are enhanced by the use of small gap angles, namely, the effect of axial motion of the cone (described above) and the effect of the finite size of the holes in the stationary plate via which the pressure is measured. The pressure error caused by the latter is difficult to estimate theoretically but from the consistency of measurements made using a rotating plate at various separations from the stationary plate it appears to be negligible if the separation of the plates exceeds 3 times the hole diameter. This sets a lower limit to the permissible gap angle if the radius of the cone is fixed. In the present apparatus the hole diameter is 0·5 mm and the radius of the cone is 4·4 cm.

In place of the usual method of pressure measurement with capillary tubes, diaphragm pressure gauges are used. These have the advantage, over capillaries, of quicker response time because they require a smaller volume flow of liquid, but the disadvantage of greater temperature sensitivity which necessitates very close temperature control.

A 2 per cent solution of Perspex (M.W.$\sim 10^6$) in dimethyl phthalate is being studied by the foregoing method. At low shear rates ($<3$ sec$^{-1}$) steady values of pressure are reached within $\sim 1$ minute of the commencement of rotation but at higher shear rates ($> \sim 5$ sec$^{-1}$) large transient pressures are observed which require up to 1 or 2 hours to grow and decay. In these cases it is the steady pressure, after the decay of the transient which was measured.

The radial pressure distribution with a rotating plate is almost linear except at the lowest angular velocities when it is concave to the radius axis. With a rotating cone (semi angle 86·8°) the pressure varies as log $r$ only under the outer part of the cone where the gap is sufficiently large compared with the hole diameter. Significantly negative pressures are observed at the rim for both rotating plates and cones.

Numerical results will be presented and compared with the predictions of the network theory of polymer solutions.

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## Normal Stress Measurements on Aluminium Laurate Solutions using a Weissenberg Rheogoniometer

By P. L. LANGBONRE and A. A. MILNE (National Engineering Laboratory, Thorntonhall, Lanarkshire)

As a preliminary to the study of the effects of the rheological properties of lubricants on performance in bearings, the properties of certain aluminium laurate solutions were investigated using a Weissenberg Rheogoniometer. Normal and tangential stresses were measured and an improved method of measuring the former is described.

Based upon analyses by OLDROYD and PASLAY a simplified treatment of the data has been evolved. This enables relaxation and retardation times to be calculated and the physical constants found in continuous rotational test methods to be verified by vibrational experiments on the same machine.

## Measurements of Normal Stresses and Viscosities in Visco-Elastic Fluids

By J. J. BENBOW and E. R. HOWELLS, Imperial Chemical Industries (Plastics Division, Welwyn Garden City, Herts.)

The Weissenberg-Roberts cone and plate rheometer is used to study the viscous and elastic properties of some polydimethylsiloxane fluids as a function of rate of shear and of temperature.

The experimental method is described and emphasis given to the necessity of precision in the mechanical adjustments of the cone-and-plate ; the limitations set by the occurrence of non-laminar flow at large shear strains are stated.

It is found that the normal stress is small compared to the tangential stress at low rates of shear but at high rates the normal stress is the larger ; that is, the curves representing the shear rate variation of these stresses

cross. The value of the stresses at the cross-over is found to be independent, to a good approximation, of molecular weight and of temperature.

Similar experiments with molten polythene provide a comparison between the two types of polymer.

Previous theoretical work by other workers is discussed in the light of the present results.

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## Stress Relaxation, Flow and Recovery in Vulcanised Rubber at Ambient Temperatures

By A. N. GENT (British Rubber Producers' Research Association, Welwyn Garden City, Herts.)

*Introduction.* The following forms of delayed response occur in vulcanised rubbers :

(i) When a constant deformation is imposed, the stresses set up gradually decrease with time. This is the phenomenon of *stress relaxation*.

(ii) When a constant stress is imposed, the resulting deformation increases continuously. This is known as *creep*, or drift.

(iii) When the stress is eventually removed, the unstrained state is not regained immediately. The deformation that remains is known as *set* ; it gradually decreases. The deformation that is recovered, i.e., the amount of *recovery*, correspondingly increases with time.

(iv) Under small sinusoidally-varying stresses, the deformation lags behind the instantaneous stress by a constant (phase) angle, whose tangent affords a measure of *hysteresis*.

These are presumably four manifestations of a single relaxation process. Their inter-relation presents an initial problem.

*Relationship between the rates of stress relaxation, creep and recovery.*

The rates of creep $C$ and recovery $R$ are related to the rate of stress relaxation $S$ as follows :

$$C = -AS \qquad (1)$$

$$R = -BS \qquad (2)$$

where $A$ and $B$ are specific properties of the relation between stress and deformation at constant time. If the relation in linear, i.e. for Hookean elastic behaviour, $A$ and $B$ both take the value unity and the three rates are numerically identical. When the stress-strain relation is non-linear, however, as it is for vulcanised rubber in simple extension and for many

other rheological materials, the values of $A$ and $B$ may differ considerably, both from unity and from each other, leading to considerable differences in the rates of creep, stress relaxation and recovery.

Measured rates for natural rubber vulcanisates are found to be in good accord with those predicted by equations (1) and (2), the values of $A$ and $B$ being calculated from the Mooney form of stored (strain) energy function. The rate of stress relaxation is largely independent of the imposed extension in the range 0 to 200 per cent ; it may thus be considered a more fundamental measure of the relaxation process.

*Relationship between the rate of stress relaxation and hysteresis.* Measurements of hysteresis for a number of vulcanisates are in good agreement with the values calculated from the corresponding rates of stress relaxation, by means of an assumed distribution of relaxing elements. The two properties, hysteresis and stress relaxation, thus clearly arise from the same visco-elastic mechanism.

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*Relaxation Mechanisms.* Four relaxation mechanisms have been distinguished, apart from irrecoverable viscous flow which appears to be negligible in vulcanised rubber. They are :

(a) The attainment of equilibrium in a crosslinked network. The measurements are concerned with the final stages of this process, where the stress decay is substantially proportional to the logarithm of the elapsed time in the deformed state. The rate of decay is found to depend very strongly on the degree of crosslinking of the vulcanisate, becoming too small to measure accurately for tightly crosslinked rubbers. On the other hand, the vulcanisation system, i.e. the nature of the crosslinks, does not generally influence the relaxation process.

(b) The second relaxation mechanism arises from oxidative scission of network chains. It may be clearly distinguished from the first, since it follows a different, increasing, time dependence.

A striking observation is that the secondary creep is recovered almost completely (in addition, of course, to the primary creep) in materials where oxidation results primarily in chain scission. The severed chains obviously do not prevent the residual molecular network from regaining the unstrained state. In other cases, where scission is accompanied by crosslinking in the strained state, the secondary creep is only partially if at all recoverable.

(c) A marked increase in the rate of stress relaxation is found at high extensions, of 300 per cent or more. It is attributed to a new relaxation mechanism, namely the gradual ordering of parts of the molecular chains into a crystalline arrangement.

(d) In vulcanisates containing large amounts of carbon black, the rate of stress relaxation is large at all extensions, indeed, of the same order as is observed in unfilled vulcanisates at the highest extensions. It has previously been proposed that the deformation of filled rubber is virtually confined to small " softened " regions, having similar

properties to the unfilled vulcanisate. The extensions there are correspondingly high (up to several hundred per cent) even when the imposed overall extension is small. It thus appears that stress relaxation in filled vulcanisates takes place primarily in the softened regions, at rates appropriate to the high local strains.

## The Dynamic Mechanical Behaviour of some Bitumens

By E. N. THROWER (Road Research Laboratory, Harmondsworth, Middlesex)

The behaviour of a range of bitumens under dynamic (sinusoidal) loading has been measured over the frequency range 5–500 c/s, at temperatures between $-20°C$ and $+40°C$. The apparatus uses a moving-coil vibrator to produce the force, which is applied axially to one end of a cylindrical specimen. The voltages generated by a piezo-electric load gauge supporting its fixed end, and by a piezo-electric displacement gauge coupled to its driven end, are measured with a phase-sensitive voltmeter. The ratio of these voltages is converted to the dynamic modulus by comparison with the value obtained using a statistically calibrated steel spring. Bitumens whose viscosity is too low to permit them to be tested unsupported are tested in shear in the annulus between two concentric cylinders, the inner being connected to the driver, and the outer to the load gauge. The whole vibrator assembly is contained in an air thermostat controlled to about $\pm 0{\cdot}1°C$.

The results showed that the method of reduced variables due to FERRY, TOBOLSKY and others was in general applicable to these materials, i.e. that a change in temperature is equivalent to a change in frequency from $f$ to $af$. The method thus yields (a) curves giving the effect of frequency on $J^*$, and (b) a curve of the shifting factor $a$ against temperature, giving the effect of temperature on relaxation and retardation times.

Plots of the complex compliance produced by this method, however, showed in some cases divergences in the value of the real part $J'$ at low temperatures and high frequencies ; reduction was still possible for the imaginary part $J''$ and the low frequency end of the curves for $J'$ lay along a common envelope.

In order to check the validity of this reduction, low temperature measurements of the complex compliance of one material were made at high frequencies (by a resonance technique), and these confirmed the divergence of $J'$ from the common envelope under these conditions. Such a direct test was not possible at the low frequency end of the data ; the lowest reduced frequency was $10^{-2}$ c/s, and the apparatus could not be used at such frequencies. Instead, repetitive " square-wave " loads were applied, and the results analysed by Fourier methods to yield the two parts of the complex compliance. Excellent agreement was found between the values of $J'$ and $J''$ measured in this way, and those predicted by the method of reduced variables.

The effect of temperature on relaxation times in the bitumens, as given by the curve of the shifting factor log $a$ against temperature is, however, not given by Ferry's equation :—

$$\log a = \frac{-C_1(T-T_2)}{C_2+(T-T_2} \qquad (1)$$

in which $T_2$ is a reference temperature, and $C_1$ and $C_2$ are (approximately) universal constants.

This equation can be rewritten as :—

$$(\log a + C_1)\,(T-T_2+C_2) = C_1C_2 \qquad (2)$$

i.e. a hypobola whose shape is controlled by $C_1C_2$. According to FERRY's free volume interpretation of $\alpha_2$ (1) $C_1C_2$ is equal to $\alpha 2$, the temperature coefficient of free volume ; materials having the same value $\alpha_2$ thus give different sections of the same hyperbola. The values of log $a$ for the bitumens can all be fitted to hyperbolae of the form of (2) at the higher temperature, with values of $\alpha_2$ ranging from $2{\cdot}0$ to $4{\cdot}5+10,^{-4}$ as compared with the approximately " universal " value of $4{\cdot}8+10^{-4}$ found by FERRY.

At lower temperatures, the curves diverge from equation (1). Values of log $a$ derived from viscosity measurements at the higher temperatures (15°C to 80°C) also fit hyperbolae of the form of (2) with similar values of $\alpha_2$ ; no viscosity data at low temperatures are available.

In view of the known failure of eqn. (1) at temperatures near the glass transition, measurements were made of the specific volume/temperature relation down to about −38°C. In no case was a clear-cut transition found. A linear specific volume/temperature relation existed at higher temperatures, but the transition region below this was curved over a very wide range of temperature. The second linear region which presumably exists below the transition lay below the lowest available temperature. Experimental values of $\alpha_2$ (assuming this is given by the difference between coefficients of expansion above and below $T$ ) for comparison with those found from eqn. (2) could therefore not be obtained. Values of the temperature of onset of the curvature could not be used to produce coincidence of the curves of log $a$, as can the values of $T$ for polymeric and other materials.

Equation (1), and the associated free-volume theory, was developed for chemically homogeneous materials. Bitumens contain a very wide range of chemical types, with molecular weight estimates ranging from about 1000, up to about 100,000. Except at low temperatures (near the highest effective glass transition of any of the constituents), this heterogeneity appears not to affect the behaviour ; the temperature dependence of all relaxation processes appear to be identical, and are given by an equation of the form of (1).

The validity of the method of reduced variables is further confirmed by excellent agreement between the logarithmic retardation distribution functions calculated from $J'$ from $J''$, and from creep measurements. The distributions found show compliances of the same magnitude as polymeric materials, and the curves are similar to those observed for polymeric



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materials of relatively low molecular weight. Except possibly for a heavily blown bitumen (behaving rheologically as a gel), they do not agree with the Rouse-Bueche theories, possibly because friction coefficients of the various chains differ.

## The Rheology of Filler Loaded Vulcanisates

By A. R. PAYNE (Research Association British Rubber Manufacturers, Shawbury, Shrewsbury, Shrops.)

Earlier work on the dynamic properties of filler loaded vulcanisates showed up a type of non-linearity. The non-linearity is such that the dynamic modulus, internal friction and resilience of the rubber depend on the amplitude of vibration. It is noted however that at any one shear amplitude, the stress-strain curve is linear, the response to a sinusoidal straining is a sinusoidal stress, without any evidence of the harmonic content that would be expected if non-linearity of a type not associated with " structure " breakdown was present. The non-linearity only becomes evident when the amplitude is changed and these non-linear effects depend on the time schedule of the measurement and the deformation history.

The paper includes a discussion of the variation with the amplitude of straining of the modulus of carbon black loaded rubber vulcanisates. The range of strain is from 0·002 per cent to 1·0 per cent. The experimental results show some interesting new features. One of the most important is that a yield point exists at low strains, the strain at which the yield point occurs being dependent on the concentration of the carbon black. At strains lower than the yield point strain the vulcanisates behave almost elastically (tan $\delta$ being approximately that of the pure gum) with the modulus independent of the strain. The results show clearly the existence of a yield point typical of non-linear thixotropic systems. The yield point occurs at very much lower strains than those at which the " Mullins " effect has been previously demonstrated.

The decrease in modulus with strain amplitude may be interpreted in terms of a breakdown of structure, analysis of the experimental curve shows striking similarities to the behaviour of non-Newtonian liquids on shearing, and indeed many of the approaches developed in the rheological literature[1] to described non-Newtonian behaviour can be used to describe the non-linear behaviour of the carbon black loaded vulcanisates.

The paper discusses the use of the analogy between the change of viscosity with velocity and the change of elasticity with strain, and shows how the structure changes can be interpreted in terms of the breakdown of carbon black chains and agglomerates.

It was found that plots of $f(G) = \ln G/G_\infty \ln G_o/G_\infty$ were linear when the function $f(G)$ was plotted on probability paper[2] against either stress or strain. $G$ is the shear modulus in the linear region at very low strains.

$G_\infty$ is the value of the shear modulus at very high strains. The success of the plot implies that a Gaussian relationship exists between the variation of the logarithm of the modulus and strain ; this is interpreted as a Gaussian distribution of bond strengths.

The variation of $G_0$ and $G_\infty$ with the concentration of carbon black was found to be exponential. The $G_\infty$ values were compared with those expected from the hydrodynamic interaction of spheres in a rubber, and a factor was obtained from swelling measurements to account for additional cross linking between the rubber and the carbon black.

The variation of the modulus with temperature was also studied, and a linear relationship between modulus and reciprocal temperature over a temperature range of about 90°C allowed values of the activation energies to be obtained. The values range up to 2·0 k.cal/mole, showing the existence of weak links.

A study of the effect of heat treatment of natural rubber vulcanisates showed that $G_0$ decreases with temperature of heating due, presumably, to thermal break-up of carbon black chains and agglomerates.

The variation of modulus with the type of carbon black was also studied and a relationship was shown to exist between modulus values and the agglomeration and shape factors of the carbon black.

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## Section A

## THEORETICAL

**401. Theory of anisotropic fluids.** J. L. ERICKSEN, *Trans. Soc. Rheol.*, 1960, **4**, 29–39. The Johns Hopkins University, Baltimore, Maryland. The paper summarizes recent work on theories of anisotropic fluids, drawing attention to a class of theories whose predictions resemble observed behavior of polyisobutylene solutions in steady shear flow. Further research will be required to determine how well these theories can describe the behavior of such fluids. It seems rather likely that they will do well in describing many steady flow situations. From what is known of the linear behavior of such fluids, it would seem that a theory adequate for vibration problems should include linear viscoelasticity theory as a special case. Since the theories discussed seem not to, they may well be found wanting when applied to situations commonly thought of as dynamic. Author

**402. Thermodynamics of stretching of nylon fibers.** M. L. WILLIAMS, *Trans. Soc. Rheol.*, 1960, **4**, 297–313. Research Center, The Chemstrand Corporation, Decatur, Alabama. The thermodynamics of the reversible stretching of an elastic body is reviewed, and its application to the theory of rubberlike elasticity and to semicrystalline polymers is discussed. Experimental data are given for the stress-temperature behavior of undrawn nylon filaments extended from 2 to 50% at 160°C. It is found that a large proportion of the total elongation remains as a quasi-permanent orientation. That part of the total extension which is immediately recoverable on removal of stress at the end of the stress-temperature experiment is used to define the strain to be used in the thermodynamic analysis. This definition is rather arbitrary since time effects are not considered. The thermodynamic effects of volume changes during the deformation are eliminated in a manner similar to that used for rubber by converting from stress at constant length to stress at constant elongation. The result is that the stress is primarily accounted for by an entropy term above 80°C, indicating that nylon is rubberlike, at least in thermodynamic terms. The resulting stress-strain curves can be approximated by a form of the equation predicted by the theory of rubberlike elasticity. However, the calculated modulus ($3 \times 10^9$ dynes/cm.$^2$) leads to a molecular weight between crosslinks much too low. If the crystallites were acting as fillers to the amorphous rubbery chains, the magnitude of this discrepancy would be lessened. Author

**403. Stress analysis for linear viscoelastic materials with temperature variation.** L. W. MORLAND, E. H. LEE, *Trans. Soc. Rheol.*, 1960, **4**, 233–263. Brown University, Providence, Rhode Island. The system of equations is presented which determine the stress and strain distributions for a linear viscoelastic material with varying temperature. Temperature influences on viscoelasticity are represented by a shift relation on the logarithmic time scale which equates temperature change to a translation on the logarithmic time scale for all viscoelastic functions. Methods of treating the general equations are discussed, but solution by standard methods is shown to be possible only for restricted situations. Stresses in a cylinder of incompressible material under a steady axisymmetrical

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## Section A

## THEORETICAL

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temperature distribution are evaluated when a constant internal pressure is suddenly applied and maintained. Because of the assumption of incompressibility, thermal stresses due to inhomogeneous expansion do not appear, but the temperature effect on viscoelastic response produces a marked effect on the stress field as compared with the isothermal case. Particular features of the stress distributions for Kelvin and Maxwell materials are contrasted. An approximate method of solution applicable to the Maxwell body and more general viscoelastic materials is described.
Author

**404. On anomalies in the measurement of the complex modulus.** S. R. BODNER, *Trans. Soc. Rheol.*, 1960, **4**, 141–157. Brown University, Providence, Rhode Island. Resonance tests on aluminum and lead specimens reveal multiple resonance peaks, i.e., resonances in addition to the natural frequencies of the system, when the specimens are subjected to uniform static stress or contain residual stresses. The multiple resonance peaks can be interpreted in the same manner as the resonance dispersions observed by Fitzgerald. Experiments have been carried out which show that the phenomenon is directly related to the presence of either residual or applied static stresses. A tentative explanation of the phenomenon is presented which is based upon the mathematical representation of the experiments by Mathieu-type equations. The additional resonances are interpreted as instabilities of the solution of the Mathieu equation.
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**405. Relations between hypo-elasticity and elasticity.** B. BERNSTEIN, *Trans. Soc. Rheol.*, 1960, **4**, 23–28. U.S. Naval Research Laboratory, Washington, D.C. The equations of hypo-elasticity are not in general sufficient to define a material. It is necessary in addition to indicate one stress-strain configuration. Conditions may be written which test whether any or all materials satisfying a given set of hypo-elastic equations are elastic in the sense of Cauchy or in the sense of Green. If the hypo-elastic material is a work hardening material, it must be elastic in the sense of Green.
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**409. Propagation of elastic-plastic waves in a non-homogeneous medium.** P. PERZYNA, *Archiwum Mechaniki Stosowanej*, 1959, **11**, 595–613.



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**410. Linear theory of plasticity of anisotropic bodies and its applications to problems of limit analysis.** A. SAWCZUK, *Archiwum Mechaniki Stosowanej*, 1959, **11**, 541–557.

**411. A general theory of piecewise linear plasticity for initially anisotropic materials.** I. BERMAN and P. G. HODGE, *Archiwum Mechaniki Stosowanej*, 1959, **11**, 513–541.

**412. On some basic aspects of the theory of non-homogeneous loose and cohesive media.** W. OLSZAK, *Archiwum Mechaniki Stosowanej*, 1959, **11**, 751–767. Some aspects of soil mechanics and limit design raised in previous papers are developed further. P.F.

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**413. Stress propagation in an infinite viscoelastic body produced by a time dependent point force.** W. NOWACKI, *Archiwum Mechaniki Stosowanej*, 1959, **11**, 715–729.

**414. Axial plastic flow between non-circular cylinders.** V. V. SOKOLOWSKY, *Archiwum Mechaniki Stosowanej*, 1960, **12**, 173–185. Institute of Mechanics, Academy of Sciences of the USSR, Moscow. (Author's address.) The flow space is represented by a volume bounded by two confocal ellipses. A linear stress-strain relation is first assumed, and a method is indicated by which it is possible to reduce the problem to the linear one in the case of a non-linear plasticity relation. P.F.

**415. Analytical integration of the differential equation of water storage.** V. M. YEVDJEVICH, *J. Res. Nat. Bur. Stand.*, 1959, **63B**, 43–52. The integration of the storage differential equation is usually done by graphical or numerical procedures. This paper gives an approach to the analytical integration of that equation. M.F.C.

**416. Compressible turbulent boundary layers with heat transfer and pressure gradient in flow direction.** A. WALZ, *J. Res. Nat. Bur. Stand.*, 1959, **63B**, 53–70. A treatment based upon the von Karman-Pohlhausen principle, and empirical laws for dissipation and for turbulent wall friction, yields results in satisfactory agreement with the available experimental data. M.F.C.

**417. Absorption of sound of finite amplitude in a relaxing medium.** A. L. POLIAKOVA, *C.R. Acad. Sci. USSR*, 1958, **122**, 51–53. [Russian]

**418. A study on the determination of the drain diameter in drainage theory.** K. K. WATSON, *Aust. J. Appl. Sci.*, 1960, **11**, 108–121. School of Civil Engineering, University of New South Wales, Sydney. Various theoretical solutions, based on hodographic analyses, have of late enabled the problem of soil drainage to continuous drain tubes to be completely determined. The usual requirements from such analyses are the position of the water-table and the diameter of the drain. This paper presents a detailed study of the latter discussing initially the concept which is used

to determine the diameter of the drain, namely, the specifying of an equipotential line which may be considered to be replaced by the drain periphery. Particular reference is made to the necessity for fully defining this equipotential line. Equations, based on van Deemter's hodographic analysis, are presented enabling the drain diameter to be accurately determined for cases including and excluding the capillary fringe. The results include an investigation of the $\delta$ parameters, a full solution (given in graphical form) of the drainage problem over the $q/K$ range 0·10–0·01 for zero capillary fringe thickness, and a consideration of the effect of the capillary fringe on the diameter of the drain for the optimum condition. Author

**419. On the theory of the development of real microcracks in solids subjected to deformation.** D. I. SHILKRUT, *C.R. Acad. Sci. USSR*, 1958 **122**, 69–72. [Russian]

**420. On the role of external stress in recovery at plastic deformation.** M. B. MAKOGON *et al.*, *C.R. Acad. Sci. USSR*, 1958, **122**, 221. [Russian]

**421. A new law of creep rupture.** I. A. ODING and V. N. GEMINOV, *C.R. Acad. Sci. USSR*, 1958, **122**, 222–226. [Russian]

**422. Two-dimensional problem of the motion of a visco-plastic dispersed system between two planes at an acute angle.** A. KH. KIM and M. P. VOLAROVICH, *Kolloidnyi Zh.*, 1960, **22**, 186. Kalinin Peat Inst., Belyorossian Polytechnic Inst. [Russian, English abstract]

**423. On the question of the Weissenberg effect.** N. I. MALININ, *Kolloidnyi Zh.*, 1960, **22**, 201. Inst. of Hydrodynamic, Siberian Nat. Acad. Sci., Novosibirsk. In determining stresses of visco-elastic liquids with the aid of Mohr's ring it has been shown that the Weissenberg effect in which normal stresses are generated during shear should take place not only with high molecular solutions but with any disperse system possessing some resiliency of form. Equations have been derived for calculating the normal pressures in the Weissenberg effect for Maxwell and Burgers models of visco-elastic bodies. In the case of a Maxwell body the equations coincide with those derived by Weissenberg. The normal pressures of the Weissenberg effect arising in the gap between two discs of which one is revolving and the other motionless have been calculated for the case when the radial pressure is equal to the axial. The axial forces in the Weissenberg effect have been calculated for the cases of the relative rotation of two discs and of a disc and a cone. [Russian, English abstract] Author

**424. Concerning the maximum stress for constant velocity deformations.** I. I. GOL'BERG, *Kolloidnyi Zh.*, 1960, **22**, 249. Scientif. Res. Inst. for Rubber and Latex Wares, Moscow. An interpretation has been presented of maximum stress during deformation at constant rate, based on the assumption of the existence of equilibrium internal stress. Preliminary stresses of such type may arise during operation with a rotation viscometer with small clearance. The assumption requires experimental proof. [Russian, English abstract] Author



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**425. Viscosity increments of non-ionized molecules.** A. POLSON, *Nature, Lond.*, 1960, **187**, 482–483. C.S.I.R., and University of Cape Town Virus Research Unit, Medical School, Capetown, S.A. From the viscosity increments of low molecular weight substances, it is noted that, as expected, the departure from the macroscopic friction law of Stokes becomes more pronounced the more closely the molecular diameters of the dispersed particles approach those of the dispersion medium. The viscosity increments of macromolecules, however, are independent of molecular volume. An equation relating the intrinsic viscosity and the diffusion constant of a protein to its mol. wt., previously deduced by the author, has been revised. It is suggested as a means of molecular weight determination without a knowledge of the partial specific volume of the protein. W.G.C.

**426. The coupling of polymers. Part 1. Size distributions and intrinsic viscosities.** C. H. BAMFORD and A. D. JENKINS, *Trans. Faraday Soc.*, 1960, **56**, 907–931. Courtaulds Limited, Research Laboratory, Maidenhead, Berks. Theoretical. A general expression is derived which enables the ratio of the final and initial mean degrees of polymerization to be deduced from intrinsic viscosity measurements. W.H.B.

**427. Theory and analysis of peel adhesion : bond stresses and distributions.** D. H. KAELBLE, *Trans. Soc. Rheol.*, 1960, **4**, 45–73. Central Research Department, Minnesota Mining and Manufacturing Company, St. Paul, Minnesota. A previous theory is extended to provide expressions, general with respect to stripping angle, for the boundary stresses and bond stress distributions. The treatment is developed in terms of two stress mechanisms. Boundary cleavage involves tension-compression stress and predominates at high angles of peel. At some low range of peel angles, prediced from theory, boundary shear provides the controlling mechanism. Measurement of peel force as a function of angle of peel and rate identify the transition in failure mechanism from cleavage to boundary shear and provide comparison data for theoretical force-angle functions. The results of direct measurement of the internal cleavage stresses, by means of a new experimental device termed the " split-beam transducer ", further characterize this bond failure mechanism.
Author

**428. The peeling force of adhesive joints.** F. S. C. CHANG, *Trans. Soc. Rheol.*, 1960, **4**, 75–89. Mystik Adhesive Products, Inc., Northfield, Illinois. Peeling of adhesive joint is mechanically a process of stretching the adhesive strings in the region of deformed adherend, and can be treated as multiple-specimen stretching. By using a three-element mechanical model to represent the adhesive, practical expressions of peeling force and stress in the string are derived for various geometrical arrangements conventionally used in different peeling tests. Application of these expressions will yield (1) analysis of peeling force in terms of nature of the adherend, viscoelastic characteristics of adhesive, peeling speed, and apparent interfacial force ; (2) a group of parameters for characterizing adhesive ; and (3) open up a way to study a number of interesting factors, e.g., surface condition of adherend, wetting property of adhesive, and dwelling time. Author

**429. Flow down an inclined plane.** R. D. HOFFMAN and R. R. MYERS, *Trans. Soc. Rheol.*, 1960, **4**, 119–129. Department of Chemistry, Lehigh University, Bethlehem, Pennsylvania. The flow of Newtonian and shear-thinning liquids down an inclined plane was studied with the objective of estimating the degree of shear sensitivity from a simple test. An empirical relation called the Flow Decay Curve was obtained, by means of which a wide variety of materials was characterized by the decrease in velocity of the advancing front with distance of flow. In general the decrease was an exponential function of distance, and the magnitude of the exponent provided an index of shear thinning, independent of viscosity. The Flow Decay Curve was compatible with a theoretical equation based on hydrodynamic flow principles.

Author

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**430. The effect of network flaws on the elastic properties of vulcanizates.** J. SCANLAN, *J. Polym. Sci.*, 1960, **43**, 501–508. Research Association of British Rubber Manufacturers, Shawbury, Shrewsbury, Shropshire. A treatment is given of the effect of network flaws due to the finite chain length of the primary elastomer molecules on the elastic properties of rubber vulcanizates. Full allowance is made for the elastically inactive material which exists either as sol or as loose ends. The cases of linear primary molecules with either a random distribution of lengths or with uniform lengths are considered and the results compared with those of earlier theoretical treatments. Author

**431. An extension of Goodee's impulse theory of viscosity to pseudoplastic systems.** T. GILLESPIE, *J. Colloid Sci.*, 1960, **15**, 219–231. Physical Research Laboratory, 2–280 Building, The Dow Chemical Company, Midland, Michigan. An attempt has been made to derive a theory of pseudoplasticity which may be used as a guide in combined studies of rheology and flocculation kinetics. The shear stress—shear rate relation obtained is a more general form of the Williamson empirical equation for pseudoplasticity. Some experiments with a thickened pseudoplastic latex (polystyrene) are used to illustrate the application of the theory. R.B.B.

**432. Irreversible thermodynamics and continuum mechanics.** A. CEMAL ERINGEN, *Phys. Rev.*, 1960, **117**, 1174–1183. Purdue University, Lafayette, Indiana. Principles of irreversible thermodynamics are recapitulated. Using the basic conservation principles and the principles of irreversible thermodynamics, the fundamental equations and constitutive relations are obtained for fluids, solids and visco-elastic media. R.B.B.

**433. Theory of viscoelasticity of amorphous polymers—III. Dispersion of dynamic bulk modulus.** O. NAKADA, *J. Polym. Sci.*, 1960, **43**, 149–165. Hitachi Central Research Laboratory, Kokubunji, Tokyo, Japan. Relaxation phenomena associated with volume changes in amorphous polymers are attributed to the configurational relaxation of chain molecules in three dimensions. A molecular model is used to derive a diffusion equation for the molecules and a dynamic pressure-volume relation

calculated by integration of the diffusion equation over a sinusoidal pressure cycle. The real and imaginary parts of the bulk modulus are derived. The dispersion of bulk modulus is specified by two characteristic time constants which relate respectively to entropy and internal energy changes during deformation. A preliminary comparison is made of the theory with experiment. E.H.A.

## Section B

## INSTRUMENTS AND TECHNIQUES

**434. Foam viscometer.** R. J. FRENCH, *J. Sci. Instrum.*, 1960, **37**, 307–308. D.S.I.R. and Fire Offices' Committee Joint Fire Research Organisation, Boreham Wood, Herts. The critical shear stress of foams used in fire-fighting is determined in an instrument consisting essentially of a rotating torsion wire and vane which dip into the foam sample. The torsion wire is selected to give an instrument constant suitable for the range of critical shear stresses being measured. This apparatus permits rapid determinations to be made, readings being taken only ten seconds after collection of the foam. W.G.C.

**435. Studies on the interfacial viscosities of monolayers.** J. T. DAVIES and G. R. A. MAYERS, *Trans. Faraday Soc.*, 1960, **56**, 691–696. Dept. of Chemical Engineering, Pembroke Street, Cambridge. A new interfacial viscometer has been developed to measure accurately the viscosities of monolayers at the oil-water interface. It can be used to study films of interfacial viscosities from $1 \times 10^{-4}$ to $10^{-1}$ g sec$^{-1}$. Measurements on proteins and on solutions of cetyl alcohol and of sodium lauryl sulphate are reported. W.H.B.

**436. Rheological measurements with the Brabender plastograph.** C. C. MCCABE, *Trans. Soc. Rheol.*, 1960, **4**, 335–346. E.I. du Pont de Nemours & Company, Inc., Elastomer Chemicals Department, Wilmington, Delaware. The Brabender Plastograph provides a simple, rapid, precise characterization test for rheological properties of elastomers. These are determined at shear rates which nearly approximate those of industrial applications. The dependence of flow characteristics upon both shear rate and temperature is illustrated and gives good agreement with the Ostwald de Waele relation. Values for the activation energy of flow were computed for neoprene from the flow rate temperature coefficient at constant stress and averaged 10·2 kcal./mole. Author

**437. Instrumentation in the paper-making industry.—Part 2. Measurement and control of paper stuff consistencies.** F. CHURCH, *Instrum. Pract.*, 1960, **14**, 48–53.

**438. Yield stress exerted on a body immersed in a Bingham fluid.** G. BOARDMAN and R. L. WHITMORE, *Nature, Lond.*, 1960, **187**, 50–51. Dept. of Mining and Fuels, University of Nottingham. In a Bingham fluid, a body should move only when the difference between its density and that of the fluid is sufficient for it to develop a force greater than the

yield stress. This limiting force has been determined with glass rectangular blocks (suspended with their faces horizontal and vertical) in a 20% suspension of kaolinite clay. The yield stress on horizontal faces was 145 ± 15 dyne $cm^{-2}$ and on vertical faces 29 ± 3 dyne $cm^{-2}$. Thus for suspensions of this type yield stresses obtained from viscometer measurements (e.g. 52 dyne $cm^{-2}$ with a Ferranti rotating-cylinder viscometer) may not be of much use in predicting instability towards bodies immersed in them. W.G.C.

**439. The torsiometer—an instrument for the study of gels considered as elastic solids.** W. A. SOUTHORN, *J. Sci. Instrum.*, 1960, **37**, 292–296. Rubber Research Institute of Malaya, Kuala Lumpur, Federation of Malaya. A new instrument has been developed for studying changes in development of structure in the weak hydrogels produced when natural rubber latex from *Hevea braziliensis* is coagulated. The instrument records on a chart the progressive changes in torque required to give a fixed small value of deformation in an annular sample. The machine can be used for gel systems other than rubber, and may therefore have applications in other fields. Results may be expressed directly as a modulus of rigidity for materials with properties approximating to those of an elastic solid. For visco-elastic materials the modulus is a complex function including viscosity components. The range of sensitivity of the instrument is from 1 to $10^5$ dyne $cm^{-2}$. Author

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**440. A simple method of investigating the creep of metals under simple shear.** E. N. DA C. ANDRADE, *Nature, Lond.*, 1960, **187**, 494. Dept. of Metallurgy, Imperial College, London, S.W.7. Two parallel rectangular grooves are cut in a metal plate. The outer sections of the plate are gripped firmly, while a force is applied to the centre section in the plane of the plate and parallel to the grooves. It is suggested that this method may be applied in the industrial study of creep and fatigue in metals. W.G.C.

**441. Survey of various special tests used to determine elastic, plastic and rupture properties of metals at elevated temperatures.** F. GAROFALO, *Mech. Engng. NY*, 1960, **82**, 102. I.O.A.

**442. Dynamic distribution of strain in textile materials under high speed impact.—Part 1. Experimental methods and preliminary results on single yarns.** D. R. PETTERSON, G. M. STEWART, F. A. ODELL and R. C. MAHEUX, *Text. Res. J.*, 1960, **30**, 411–21. Biophysics Division, U.S. Army Chemical Warfare Laboratories, Army Chemical Center, Maryland. Data is presented on the distribution of strain along a nylon yarn when subjected to a high speed impact in the transverse direction. The strain front velocity is shown to be independent of the striking velocity and there is a parabolic relation between the transverse wave front velocity and the striking velocity. The strain-position distributions indicate that Hookean behaviour cannot be assumed at high rates of straining. N. W.

**443. Dynamic distribution of strain in textile materials under high speed impact.—Part 2. Stress-strain curves from strain-position distributions.**, D. R. PETTERSON and G. M. STEWART, *Text. Res. J.*, 1960, **30**, 422–31.

Biophysics Division, U.S. Army Chemical Warfare Laboratories, Army Chemical Center, Maryland. A preliminary mathematical treatment of experimental data is presented in an effort to determine a dynamic stress-strain curve for textile yarns (Nylon and Dacron) at strain rates approaching $10^6$%/sec. N.W.

**444. A Field method for determining the limiting shear stress of peat.** A. A. SIMONYAN, *Torfraya Prom.*, 1953, 24–25.

**445. Measurement of slip (*Ko*) and viscous (*Bo*) flow coefficients of permeable solids.** J. G. BIRAM, *Nature, Lond.*, 1960, **187**, 865. English Electric Co. Ltd., Marconi House, Strand, London, W.C.2. A method of determining the slip and viscous flow coefficients of permeable solids from the measurements at a single mean specimen pressure is outlined. W.G.C.

**446. Gelatin solution as a model and photoelastic material.** A. J. CARMICHAEL and A. G. DOUGLAS, *Aust. J. Appl. Sci.*, 1960, **11**, 272–288. School of Civil Engineering, University of New South Wales, Sydney. Aqueous solutions of gelatin, when set, behave in a manner which may be described as " rubber-like ". This material has good elastic properties and remarkable optical sensitivity, which makes it an ideal photoelastic material for representing body-force problems, and problems involving large elastic deformations. This paper describes important mechanical and optical properties of various gelatin mixes, and the effect on including glycerin. The behaviour of gelatin in torsion, tension, and compression, and the mechanical creep and relaxation are considered. The variation of these properties with time, temperature, and pH is discussed and sufficient information is given to enable the confident construction of models. The birefringence of gelatin solution has been known for some time, but it is unfortunate that very little detailed investigation of this phenomenon has been reported since the pioneer work of Farquharson and Hennes (1940). The present paper outlines an accurate calibration of this material, together with a discussion of the variation of optical sensitivity with time and temperature. Author

**447. Material properties studied at 4,000°F.** *Prod. Engng.*, 1960, **31**, 15. Battelle Memorial Institute. An apparatus studies properties of refractory metals, graphites, and ceramics at temperatures of 2,000 to 4,000°F. It gives such information as tensile strength and compressive stress-strain curves, as well as shear and bearing strength of specimens subjected to high temperatures. The apparatus, as yet unnamed, consists of a loading device, high temperature vacuum furnace, temperature and strain measurement devices and a power source. I.O.A.

**448. An improved micro-hardness tester for high-temperature use.** J. H. WESTBROOK, *Bull. Amer. Soc. Test. Mat.*, 1960, 53-58. Micro-hardness testing is the most efficient and often the only means of obtaining information on the temperature dependance of strength of hard, brittle materials. The design, construction, and operation of an improved tester are

described. The most satisfactory indenter materials have been found to be diamond, sapphire and titanium diboride ; the latter is not available commercially in single-crystal form. I.O.A.

**449. Vickers hardness tests on curved surfaces.** H. G. HARPER, F. W. RABARTS, *Machinery, Lond.*, 1960, **96**, 1238–1240. When hardness testing with a pyramidal indenter having an included angle between facets of 136°, the question of a correction may arise when the specimen under test has a spherical or cylindrical surface, particularly if the radius is fairly small. B.S.240 gives numerical corrections for tests on balls of certain specific diameters, and examples are given here of Vickers hardness correction factors for both spherical and cylindrical surfaces, either convex and concave. It is stressed that in the case of cylindrical surfaces, the orientation of the diamond with respect to the axis of the cylinder is very important. I.O.A.

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**450. Capillary viscometer for non-Newtonian liquids.** A. W. SISKO, *J. Colloid Sci.*, 1960, **15**, 89–96. Research and Development Dept., Standard Oil Company (Indiana), Whiting, Indiana. A capillary viscometer having a wide range of shear rates (0·02 to 40,000 sec.$^{-1}$) has been developed, and factors contributing to the response of the instrument analysed. The viscometer has been used to study the flow behaviour of lubricating greases. R.B.B.

**451. Measurement of internal stresses by radiofrequency spectroscopy.** H. S. GUTOWSKY, R. A. BERNHEIM and H. TARKOW, *J. Polym. Sci.*, 1960, **44**, 143–148. Noyes Chemical Lab., University of Illinois, Urbana, Illinois, U.S.A. The shift with pressure of the $Cu^{63}$ pure quadruple resonance frequency in $Cu_2O$ has been used to measure the stress developed within a resin due to curing. The oxide was dispersed as a powder in the resin and comprised 25% or more of the mix by weight. Pressures of 2300 ± 400 p.s.i. were detected in Epon 828 resin cured at 80°C for 1½ hours. E.H.A.

**452. Excitation and attenuation of hypersonic waves in quartz.** H. E. BÖMMEL and K. DRANSFELD, *Phys. Rev.*, 1960, **117**, 1245–1252. Bell Telephone Laboratories, Murray Hill, New Jersey. A method for the generation and detection of hypersonic waves (approx. 2000 mc/sec) in quartz is given. Absorption measurements for different crystal orientations and after neutron irradiation are reported. Qualitative agreement with a phonon-phonon relaxation process is obtained. R.B.B.

**453. Recent developments in fluid flow metering.** A. Linford, *Ind. Chemist*, 1960, **36**, 107. Survey of Dall differential pressure devices, the electromagnetic flow meter and the ultrasonic flow meter. R.B.B.

## Section C

## METALS AND OTHER SOLIDS

**454. The orientation dependence of work-hardening in crystals of face-centred cubic metals.** L. M. CLAREBROUGH and M. E. HARGREAVES, *Aust. J. Appl. Sci.*, 1960, **13**, 316–326. Division of Tribophysics, C.S.I.R.O., Melbourne. It is shown that the principal features of the observed orientation dependence of work-hardening can be accounted for in terms of the likelihood of formation of Lomer-Cottrell sessile dislocations in two directions in the primary slip plane. This is deduced from the known variation of resolved shear stress with orientation, for the possible secondary slip systems, and metallographic observations of slip and deformation bands. Author

**455. The influence of temperature and strain rate on the flow stress of magnesium single crystals.** Z. S. BASINSKI, *Aust. J. Appl. Sci.*, 1960, **13**, 284–298. Division of Pure Physics, National Research Council, Ottawa, Canada. The temperature and strain rate-dependence of the flow stress of magnesium single crystals was measured in the temperature range 1·45–248°K. Some incidental observations were also made on the form of the stress-strain curves and the appearance of slip lines. The deformation characteristics show close similarity with those of the face-centred cubic metals. Author

**456. On the discontinuity in duralumin fatigue curves.** V. I. SHABALIN, *C.R. Acad. Sci., USSR*, 1958, **122**, 600–602. [Russian]

**457. Creep of cold-drawn nickel.** W. D. JENKINS and C. R. JOHNSON, *J. Res. Nat. Bur. Stand.*, 1959, **63C**, 1–18. Creep tests were made in tension under constant loads at temperatures of 300, 700, 900 and 1200°F on specimens of nickel initially cold-drawn to 40% reduction in area. None of the equations for defining the strain-time relationship proposed by other investigators was found to be suitable to express or predict the creep-test results of this investigation with high accuracy because these equations inadequately describe the changes in structure accompanying the creep processes. M.F.C.

**458. The influence of oxide films and adsorption of active medium on the creep of copper wire.** V. S. OSTROVSKY, *et al.*, *C.R. Acad. Sci., USSR*, 1958, **122**, 643–645. [Russian]

**459. The Peierls-Nabarro force and the deformation of iron and steel.** N. LOUAT, *Aust. J. Appl. Sci.*, 1960, **13**, 309–315. Aeronautical Research Laboratories, Department of Supply, Melbourne. Evidence for the existence of an appreciable Peierls-Nabarro force in iron and steel is examined. It is concluded that the observed behaviour is unlikely to follow from the presently proposed mechanism of this force and that the observed frictional stress may arise as a consequence of dislocations being in pile-ups. Author

**460. The influence of temperature and strain rate on the flow stress of annealed and decarburized iron at subatmospheric temperatures.** Z. S. BASINSKI and J. W. CHRISTIAN, *Aust. J. Appl. Sci.*, 1960, **13**, 299–308. Division of Pure Physics, National Research Council, Ottawa, Canada and Department of Metallurgy, University of Oxford, England. The influence of temperature and strain rate on the flow stress of annealed and decarburized iron in the stages of uniform defor mationhas been studied at temperatures down to 78°K. The Cottrell-Stokes law is not obeyed in iron, and the results are explainable in terms of the strong Peierls-Nabarro force in this metal. Author

**461. Correlation of the alternating stresses required to initiate and propagate a fatigue crack in mild steel.** N. E. FROST, *Nature, Lond.*, 1960, **187**, 233–234. Properties and Mechanics of Materials Division, National Engineering Lab., East Kilbride, Glasgow. Both the alternating stress required to initiate a crack in a notched specimen and that required to propagate a crack of given length can be correlated with the plain fatigue limit, if it is accepted that a crack of minimum depth 0·002 in. is formed at the plain fatigue limit. W.G.C.

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**462. The instability of plastic flow of metals at very low temperatures. II.** Z. S. BASINSKI, *Aust. J. Appl. Sci.*, 1960, **13**, 354–358. Division of Pure Physics, National Research Council, Ottawa, Canada. Evidence is presented to show that the load drops observed in most metals at very low temperatures arise from thermal instability rather than mechanical instability of the lattice. Measurements of the temperature rise are described. Author

**463. A low temperature yield instability in iron.** J. B. LEAN, *Aust. J. Appl. Sci.*, 1960, **13**, 359–375. Broken Hill Pty. Co. Ltd., Central Research Laboratories, Shortland, N.S.W. Polycrystalline specimens of a 0·07% C steel were tested in tension at liquid air temperatures. Under particular conditions of temperature and strain rate, following the upper yield point, the recorded stress descended below the lower yield stress then returned to the lower yield stress quasi-elastically thus forming a serration on the stress-strain curve. The magnitude of the serration depended on the difference between the upper and lower yield stresses, on the rigidity of the testing machine employed, and on the applied strain rate. In the discussion the mechanical stability of the tensile test during the yield point load drop is examined. The effect of adiabatic temperature increase in specimens deformed at low temperatures in boiling liquids is also discussed. Author

**464. The plastic resistance of crystals.** J. J. GILMAN, *Aust. J. Appl. Sci.*, 1960, **13**, 327–346. General Electric Research Laboratory, Schenectady, New York, U.S.A. Evidence is presented in this paper to show that crystals present a plastic resistance to dislocation motion. This has been demonstrated by direct observations of dislocations in LiF crystals by Johnston and Gilman, and in Fe-Si crystals by Stein and Low. The

plastic resistance is almost independent of dislocation velocity except at very high velocities. It is, however, strongly influenced by temperature, impurities, and radiation damage. In LiF crystals, the plastic resistance is much higher for glide on (100) planes than on (110) planes. It is shown that the yield stresses and indentation hardnesses of many crystals can be correlated with their elastic moduli, provided the crystal structure type is held constant. For example, for face-centred cubic metals the yield stress is equal to $1{\cdot}6 \times 10^{-3}$G (shear modulus) at $-200$°C. This is taken to mean that one important factor that determines the plastic resistance is the elastic modulus of a crystal. Crystal structure type also has a big effect, so the detailed structure of the core of a dislocation also influences the plastic resistance. The temperature dependence of the plastic resistance is discussed. A sharp drop in the plastic resistances of covalent crystals is observed at a temperature that is roughly equal to two-thirds of the melting temperature. It is suggested that this is because the cores of dislocations in covalent cyrstals " melt " at this temperature.

Author

**465. Glass in the laboratory.** R. W. Douglas, *Lab. Practice*, 1960, **9**, 585–591. The rheological properties of glass are discussed in relation to the manufacture of glass articles. M.F.C.

**466. Indentation strength of glass.** A. S. Argon, Y. Hori, E. Orowan, *J. Amer. ceram. Soc.*, 1960, **43**, 86–96. The tensile strength of plate and sheet glasses was investigated by means of indentation experiments with small spherical indenters. I.O.A.

**467. Strengths of acid-etched glass rods.** B. A. Proctor, *Nature, Lond.*, 1960, **187**, 492–493. Rolls-Royce Ltd., Aerophysics Laboratory, Littleover, Derby. Commercial soda-glass rods, 6–8 mm. in diameter, have been etched and broken in four point bending over a constant bending moment span of 1 in. The breaking stress is shown to increase with the amount of material removed by the etching solution. Experiments are being continued in order to study further the size and nature of surface imperfections in glasses. W.G.C.

**468. On the elastic properties of neutron irradiated quartz.** G. S. Zhdanov, V. G. Zubov, A. T. Ivanov, M. M. Firsova, *Sov. Phys. Crystallogr.*, 1960, **3**, 726–730. [In Russian] I.O.A.

**469. Fatigue resistance of sintered tungsten carbides with cobalt binder.** G. S. Kreumer, *La Métallurgie et la Construction Mécanique*, 1960, **92**, 99. [French]

**470. The elastic constants of synthetic single-crystal corundum at room temperature.** J. B. Wachtman, W. E. Tefft, O. G. Lam and R. P. Stinchfield, *J. Amer. ceram. Soc.*, 1960, **43**, 334.

**471. On the plastic deformation of quartzite.** I. S. Delitzin, *C.R. Acad. Sci. USSR*, 1958, **122**, 691–694. [Russian]

**472. Ultrasonic and strength tests of foamed concrete.** L. BRUNARSKI. *Archiwum Inzynierii Ladowej*, 1960, **6**, 117–147. Ultrasonic testing facilitates the evaluation of the elastic constants and of the heterogeneity of gas and foam concretes but, by itself, is insufficient as a means of ascertaining the strength. [Polish] P.F.

**473. Dependence of cement-aggregate bond-strength on size of aggregate.** K. M. ALEXANDER and J. WARDLAW, *Nature, Lond.*, 1960, **187**, 230–231. Cement and Ceramics Section, Chemical Research Labs., C.S.I.R.O., G.P.O. Box 4331, Melbourne C.1, Australia.

**474. Studies on the microhardness of metals. The dependence of the indentation hardness on the load.** A. M. SHAMS EL DIN, N. IBL, *Schweiz. Arch. angew. Wiss.*, 1960, **26**, 246–250. The present theories explaining the dependence of the micro-hardness on the load are shortly reviewed. None of them adequately explains such a relation. A new theory is presented postulating a back pressure from the metal surface. I.O.A.

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**475. Elastic constants of palladium from 4·2–300°K.** J. A. RAYNE, *Phys. Rev.*, 1960, **118**, 1545–1549. Westinghouse Research Laboratories, Pittsburgh, Pennsylvania. Elastic constants have been determined for a single crystal of palladium in the temperature range 4·2–300°K using an ultrasonic technique. Extrapolation of the data to 0°K gives $c^{44} = 2{\cdot}341 \pm 0{\cdot}027$, $c_{12} = 1{\cdot}761 \pm 0{\cdot}027$, $c_{11} = 0{\cdot}712 \pm 0{\cdot}003$, in units of $10^{12}$ dyne cm.$^{-2}$. The corresponding value of the Debye temperature is $\theta_o = 275 \pm 8$°K (calorimetric value, $274 \pm 3$°K). Both shear constants show an anomalous temperature dependence which can be correlated with the temperature variation of the contribution to $C = c_{44}$ and $C' = (c_{11} - c_{12})/2$, resulting from the presence of holes in the d band. R.B.B.

**476. Flow orientation and fracture strength of a model linear hard polymer solid.** C. C. HSIAO, *J. Polym. Sci.*, 1960, **44**, 71–79. University of Minnesota, Minneapolis, Minnesota, U.S.A. The effect of previous flow orientation on the solid fracture strength of a model linear high polymer is analysed mathematically. For the case of uniaxial orientation the fracture strength in the direction of orientation increases, and that perpendicular to it decreases, with increasing orientation. E.H.A.

**477. Magnetic effects on shear wave attenuation in single crystal copper.** J. R. NEIGHBOURS and G. A. ALERS, *Phys. Rev. Letters*, 1959, **3**, 265–268. Scientific Laboratory, Ford Motor Company, Dearborn, Michigan. Resonance effects in the attenuation of 15·9 mc/sec and 25·5 mc/sec shear waves in copper single crystals at 4·2°K with changing magnetic field strength are reported. R.B.B.

**478. Internal friction in iron at low temperatures.** L. J. BRUNER, *Phys. Rev. Letters*, 1959, **3**, 411–412. Institute for the study of Metals, University of Chicago, Chicago. Internal friction measurements over the temperature range of 4·2° to 350°K have been made on annealed and cold worked iron bars. The longitudinal mode of vibration using an electrostatic drive was employed. Resonant frequency was about 25 kc/sec. Internal friction was measured by a free decay method. R.B.B.

## Section D

## POLYMERS, ELASTOMERS AND VISCOELASTIC MATERIALS

**479. Rheological Properties of Molecules in Fibers.** S. CHANG, F. H. REE, T. REE and H. EYRING, *Trans. Soc. Rheol.*, 1960, **4**, 191–206. University of Utah, Department of Chemistry, Salt Lake City, Utah. Using an extensometer, the stress-strain curves and stress-relaxation curves were determined for nylon 66 at various temperatures (30–59°C) and relative humidities (28–75%). The fiber sample (monofil) was relaxed for various durations of time between successive cyclic deformations (elongation and contraction). The stress-strain curves thus obtained cross approximately at a point. It is concluded that below the convergent point, entangled molecules become disentangled (a thixotropic breakdown), and above the point hydrogen-bond formation occurs between lined-up disentangled molecules. Stress-relaxation experiments were conducted with fibers under different conditions, and it was found that there were two types of relaxations. In one type, the stress decreased with time, and in the other, it increased with time. The relaxation phenomena were qualitatively well explained by the Eyring-Halsey mechanical model consisting of a non-Newtonian Maxwell unit in parallel with a spring. The spring line, which represents the stress-strain relation for the parallel spring, was also non-Hookean. Author

**480. Some aspects of fibre physics.** R. MEREDITH, *J. Text. Inst.*, 1960, **51**, 527–537. Royal College of Science and Technology, Glasgow. Methods of determining the dimensions and density, and the optical, electrical, thermal and mechanical properties of fibres are reviewed, and the implications of such measurements are mentioned. The section on mechanical properties is concerned with their time dependence and their interpretation on a molecular basis is very briefly discussed. I.H.H.

**481. The tensile strength and tacky behaviour of polymeric liquids.** R. A. ERB and R. S. HANSON, *Trans. Soc. Rheol.*, 1960, **4**, 91–116. The Franklin Institute Laboratories for Research and Development, Philadelphia, Pennsylvania. The tensile strength of liquids appears to have considerable importance in describing tacky behavior in unfilled systems. An apparatus is described whose operation involves the rapid separation of flat plates between which the liquid is contained, the bottom plate being a block of known mass whose vertical motion is followed by a high-speed motion picture camera (4000 frames/sec.), permitting measurement of the instantaneous forces operating across the liquid coupled with a simultaneous recording of the events occurring during the plate separation. Five high molecular weight liquids, with viscosities in the Newtonian flow range of from 60 to $1{\cdot}2 \times 10^6$ poises, were studied. Photographic sequences showing five different types of tacky behavior are shown; viscous and elastic deformations, cohesive and adhesive breaks, and single and multiple filament formation (the latter with cavitation) are distinguishable in the various modes of failure. Stress analyses of film failures showed a high viscosity polyisobutylene to have a tensile strength of about 70 bars when essentially unelongated and several thousand bars when elongated 2300%. Filament elongation was seen to require more energy than cavitation and initial fiment formation in a system behaving elastically. Author

**482. Investigations on the adhesion phenomena of crepe-rubber with the metal adhesive "Leikonat".—III. Interaction of rubber with triisocyanate triphenyl methane.** A. M. MEDVEDEVA, B. V. DERYAGIN and S. K. ZHEREVKOV, *Kolloidnyi Zh.*, 1960, **22**, 217. Inst. of Physical Chem., Nat. Acad. Sci., Moscow. A study has been made of the interaction between sodium butadiene rubber and triphenylmethane triisocyanate, the base of the glue Leikonat. It has been shown that the viscosity of the rubber solutions increases by several magnitudes on addition of 3–5% isocyanate. After a given time period three-dimensional structures make their appearance. Isocyanate-containing rubber films assume the properties of vulcanizates as can be seen from their behaviour on swelling. The investigations confirm the assumption made as to chemical interaction between the rubber and isocyanate. [Russian, English abstract]

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**483. The dynamic compressibility of a rubber-sulfur vulcanite and its relation to free volume.** J. E. MCKINNEY, H. V. BELCHER and R. S. MARVIN, *Trans. Soc. Rheol.*, 1960, **4**, 347–362. National Bureau of Standards, Washington, D.C. The dynamic bulk compliance of natural rubber-12% sulfur was measured for varying static pressure (0 to 10$^{+3}$·0 bar), temperature (−30 to + 70°C), and frequency (50 to 1000 cycles/sec.). The data can be represented by reduced frequency or temperature plots, assuming viscosity is proportional to exp $\{1/\varphi\}$. $\varphi$ is a fractional free volume which can be taken as a linear function of temperature and pressure, $\varphi = \varphi_g + \alpha(T - T_g) - \beta P$. The "universal" WLF constants, $\varphi_g = 0{\cdot}025$ and $\varphi = 4{\cdot}8 \times 10^{-4}\,(^{\circ}\mathrm{C})^{-1}$, reduce the temperature-frequency data satisfactorily. A value for $\beta$ of $1{\cdot}15 \times 10^{-5}$ bar$^{-1}$ was found from the shift of the peaks of the imaginary compressibility vs. temperature at various pressures; this corresponds to a value of $dT/dp$ at constant free volume of 0·024 bar/°C which is nearly the same as the value of 0·025 found by Singh and Nolle for polyisobutylene. $\beta$ agrees reasonably well with the difference in compressibilities between the rubbery and glassy states.

Author

**484. Rupture of rubber.** H. W. GREENSMITH, L. MULLINS and A. G. THOMAS, *Trans. Soc. Rheol.*, 1960, **4**, 179–189. British Rubber Producers' Research Association, Welwyn Garden City, England. The paper describes development of work started some ten years ago on the application of an energy criterion to describe the rupture of rubber. It is shown that, by the use of an energy balance theory analogous to that proposed by Griffith to explain the fracture of glass, it is possible to correlate the rupture behavior of rubber samples of widely differing shapes and sizes. This experimental study provides a stringent test of the validity of the energy criterion for the rupture of rubber and demonstrates the basic significance of the value of the rupture energy obtained. Values of this rupture energy of the order of $10^6$ ergs indicates that, in the rupture of rubber, the irreversible dissipation of energy in highly deformed regions around the rupture path dominates the rupture process. The important role of these dissipative processes is also demonstrated by a study of the dependence of rupture energy on rate, temperature, and the nature of the rubber polymer. It is found that using Ferry's method of reduced

variables, previously applied to viscous and viscoelastic properties, the rupture energy of all the rubbers examined can similarly be described in a simple unifying way by two basic curves relating its dependence on rate, and the interdependence of rate and temperature. Author

**485. Investigations on the mechanism of film formation from vulcanized latex.—II. Film formation from butadiene-styrene latex SKS-30.** S. S. VOYUTSKII, D. M. SANDOMIRSKII, N. M. FODIMAN, R. M. PANICH and Z. M. USTINOVA, *Kolloidnyi Zh.*, 1960, **22**, 143. Elastomer Lab., Lomonosov Inst. of Fine-chemicals Technol., Moscow. The effect of the test temperature and of swelling in water vapour and vaseline oil on the strength of films from vulcanized and unvulcanized butadiene-styrene latex has been investigated. A study was also carried out on the behaviour of the films during mastication. The strength of the unvulcanized synthetic latex films is determined primarily by Van-der-Waals forces, whereas of films from vulcanized latex or vulcanized in the dry state, by the presence of a continuous molecular network typical for vulcanizates. The addition of casein to the butadiene-styrene latex brings a number of properties of the films nearer to those from natural latex. [Russian, English abstract] Author

**486. On the flow of rubber-like polymers and their mixtures with carbon black.** N. V. ZAKHARENKO, F. S. TOLSTUKHINA and G. M. BARTENEV, *Kolloidnyi Zh.*, 1960, **22**, 168. Inst. for Scientific Research in the Synthetic Rubber Ind., Moscow. The flow in the condensed phase of polyisobutylene and its mixtures with carbon blacks and of rubber mixtures has been studied with respect to temperature and stress. The existence of Newtonian flow has been established for polyisobutylene P-20 in the range of low yield values of from $10^3$–$10^4$ dynes/cm$^2$. Within this range of stresses Newtonian flow is absent in the black filled mixtures. Within the limits of stress investigated the rheological curves of the above systems are described by the Ostwald-de-Waele empirical exponential law $\epsilon = (1/\eta')\sigma^n$. The index of deviation from Newtonian flow ($n$) increases with active filler content and does not change when an inactive filler is added. The temperature dependence of viscosity for the systems investigated is described by the exponential equation $\eta = A\exp.E/kT$. The values for the activation energy of viscous flow have been determined and the elementary unit of flow has been calculat d. The temperature coefficient of viscosity and of the activation energy is independent of the nature and amount of filler. [Russian, English abstract] Author

**487. On viscosity-molecular weight relations.—II. Comparison of hydrodynamic theories.** R. KONINGSVELD and C. A. F. TUIJNMAN, *Makromol. Chem.*, 1960, **38**, 44–55. Central Lab., Staatsmijnen, Limburg, Geleen, Netherlands. Intrinsic viscosity and molecular weight data of polyethylene and polyvinylacetate fractions are analysed in relation to various theories. It was not possible to decide whether the relation between the number average mean square end-to-end distance and the number average molecular weight was linear or non-linear. A.S.L.

**488. The interpretation of transition phenomena in polymethylene terephthalate polymers.** G. FARROW, J. MCINTOSH and I. M. WARD, *Makromol. Chem.*, 1960, **38**, 147–158. I.C.I., Fibres Division, Harrogate. A series of polymethylene terephthalate polymers has been investigated by measurement of dynamic mechanical properties, nuclear magnetic resonance spectra, infra-red spectra and X-ray diffraction. These polymers show three transitions, $\alpha$, $\beta$, and $\gamma$ ; $\alpha$ corresponds to the melting point, $\beta$ is clearly the glass transtion. Consideration of dynamic loss results alone suggests that the $\gamma$ transition is connected with motions in the aliphatic part of the chain and that the $\beta$ transition is connected in some way with the phenylene carbonyl bond. The NMR results show that the $\gamma$ transition is restricted to very small intramolecular motions, whereas the $\beta$ transition is associated with considerable motions of the molecules in the amorphous regions. Infra-red data suggests that an additional preferred configuration of the $-O-CH_2-CH_2-O-$ group exists in the amorphous regions of polyethylene terephthalate. Since crystallization sets in above the $\beta$ transition it is reasonable to imply that this transition is associated with at least this configurational change. Detailed X-ray and optical examination of single crystals of cyclic tris(ethylene terephthalate) suggests that in the cyclic trimer molecules the carbonyl groups are placed in cis positions with respect to the benezne rings. Thus, the configurational changes may also involve the phenylene carbonyl bond. The most satisfactory explanation of these transitions, taking into account all the data, is that the $\gamma$ transition involves some very restricted rotation of the glycol residue and the $\beta$ transition a considerable rotation of this residue, also involving paraphenylene linkages in the amorphous material.
Author

**489. Investigation of the separation of dilute solutions of macromolecular substances.—I, II.** F. BURKHARDT, H. MAJER and W. KUHN, *Helv. Chim. Acta.*, 1960, **43**, 1192–1208, 1208–1214. Basle University. Solutions containing 1% to 3% of polystyrene and ethyl cellulose in benzene undergo phase separation and form emulsions. When subjected to shear flow above a critical shear rate the solution becomes homogeneous. Using an improved form of a previously-used concentric cylinder apparatus equipped to measure intensity and dissymetry of light scattered from a flowing solution, more careful investigations are made of the changes of light scattering in the critical shear rate region. The effects of using polystyrene fractions of different molecular weight are studied. [German]
A.S.L.

**490. On the spinning and stretching of polycondensate filaments.—I. Influence of spinning conditions on the stretching process.—II. Stretching under various conditions.** W. ROTH and R. SCHROTH, *Faserforschung*, 1960, **11**, 312–319, 365–373. VEB Thüringisches Kunstfaserwerk " Wilhelm Pieck " Schwarza, Rudolstadt 2, Germany. Tension-elongation relations are determined for polyamide and polyester filaments prepared in the form of closed loops to avoid errors due to slipping at the clamps. The maximum draw ratio is found to decrease as the rate of elongation is increased and also as the initial diameter of the filaments is decreased. Near 70°C there is a sharp change in the minimum tension necessary for



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cold drawing. Dry polyester filaments exhibit a tension-elongation diagram which has a saw-toothed form not found in the presence of water. Conditions favouring a sharp flow region also favour the formation of holes in the filament. [German] A.S.L.

**491. Visco-elastic behaviour of blood vessels of the muscular type.** V. HARDUNG and L. LASZT, *Nature, Lond.*, 1960, **187**, 330–331. Dept. of Physiology, University of Fribourg. The visco-elastic behaviour of cow carotis using periodical stresses (frequency 1–1·8 c/s.) is reported. Young's modulus was found to increase as much as four-fold after the administration of 60–70 *mM* potassium, whilst the tension increased considerably. Experiments with suprarennin and electrical excitation also showed considerable increase in tension, but only a slight increase in Young's modulus. W.G.C.

**492. Polymer solutions.—Part V. Viscosity behaviour of polymethyl acrylate in mixed solvent media.** S. GUNDIAH, N. V. VISWANATHAN and S. L. KAPUR, *J. Sci. Industr. Res.*, 1960, **19B**, 191–195. National Chemical Laboratory, Poona, India. The viscosity behaviour of unfractionated polymethyl acrylate has been examined in four solvent-non solvent mixtures at two temperatures. The dependence of the parameters, the limiting viscosity number, the slope of the viscosity-concentration plot and the Huggins' slope constant, $k'$, on solvent power is discussed. It is shown that $k'$, as a molecular weight independent parameter, is a measure of the relative effectiveness of the solvent for the particular polymer and attains a maximum value of 0·5 at the precipitation point irrespective of the polymer, solvent, nonsolvent and temperature.
Author

**493. The electrophoretic mobility and viscosity of poly(acrylic acid) and poly(methacrylic acid).** A. R. MATHIESON and J. V. MCLAREN, *J. Chem. Soc.*, Sept. 1960, 3581–3588. The University, Nottingham. The electrophoretic mobility of poly(acrylic acid) of molecular weight $2{\cdot}5 \times 10^6$ has been measured at different concentrations of polyacid and at four different ionic strengths over a pH range of 3–12. Corresponding measurements of the solution viscosity have been made. W.H.B.

**494. Investigation of certain rheological properties of some polyester resins from the point of view of photoelasticity. I.** J. T. PINDERA, *Rozprawy Inzynierskie*, 7, 361–411. On the basis of theoretical and experimental considerations improved methods for assessing the suitability of resins for photoelastic studies are proposed. [Polish] P.F.

**495. Time dependent tensile properties.—Part I. A unified perspective.** B. ROSEN, *J. Polym. Sci.*, 1960, **44**, 547–548. Westinghouse Research Laboratories, Pittsburgh 35, Pennsylvania. The submicroscopic initiation of rupture in stressed polymeric solids is discussed with special reference to time dependence, this being ascribed to molecular relaxations
E.H.A.

**496. Viscoelastic behaviour of nylon 6-6 monofilaments below room temperature.** B. A. DUNELL, A. A. JOANES and T. R. B. RYE, *J. Colloid Sci.*, 1960, **15**, 193–204. Chemistry Department, University of British Columbia, Vancouver 8, Canada. Stress relaxation and vibrational results in the temperature range 10° to −100°C are given for nylon 6–6 monofilament. The dynamic tensile modulus and stress relaxation modulus yield composite curves when the time-temperature superposition principle is applied. The reduction factor $a_T$, for the moduli are sufficiently similar for them to be represented by one function of temperature. R.B.B.

**497. Viscosity relationship in solutions of polyethylene glycols.** D. K. THOMAS and A. CHARLESBY, *J. Polym. Sci.*, 1960, **42**, 195–202. Physics Dept., Royal Military College of Science, Shrivenham, Wilts. The intrinsic viscosities of a series of polyethylene glycols were measured in water and toluene, and a relationship proposed between molecular weight and intrinsic viscosity. Values obtained for the Huggins constant below a molecular weight of 4,000 are much larger than would be anticipated for linear high polymers. Information on the variation of configuration with molecular weight has been obtained by comparing the specific viscosities with those expected from the relationships of Einstein, and Guth and Gold for spherical particles, and those of Kubin and Simha for rodlike particles. Author

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**498. Time dependence of viscosity in capillary extrusion of polyethylene. (Letter).** A. RUDIN and H. P. SCHREIBER, *J. Polym. Sci.*, 1960, **44**, 261–264. Canadian Industries Ltd., Central Research Labs., McMasterville, Quebec, Canada. Experimental evidence is presented to show that the time dependence of extrusion rate observed in the extrusion of polyethylenes is due primarily to volume and configurational changes in the melt and not to frictional heating at the piston. E.H.A.

**499. Investigation of the dynamic mechanical properties of some polyamides.** A. E. WOODWARD, J. M. CRISSMAN and J. A. SAUER, *J. Polym. Sci.*, 1960, **44**, 23–34. Dept. of Physics, The Pennsylvania State University, Pennsylvania, U.S.A. The damping, resonant frequency and dynamic modulus were measured as functions of temperature in the range 100 to 450°K on five polyamides. One of the polymers was studied over a range of water content and another swollen in methanol. The results are discussed. E.H.A.

**500. Melt viscosity of polymers. Effect of polydispersity.** F. BUECHE, *J. Polym. Sci.*, 1960, **43**, 527–530. Institute of Rubber Research, University of Akron, Akron, Ohio, U.S.A. The author's theory for the melt viscosity of high polymers is extended to include the effect of molecular weight polydispersity. It is found that, in the expression $\eta = kM_t^{3.5}$, the molecular weight average appropriate for $M_t$ lies between the weight and $z$ average. For molecular weight distributions with $M_w/M_n$ less than about two, $M_t$ is best represented by $M_w$, but above that value $M_z$ is a better approximation. Reasonable agreement with available experimental data is found. Author

**501. Determination of degree of cross-linking in natural rubber vulcanizates—Part V. Effect of network flaws due to free chain ends.** L. MULLINS and A. G. THOMAS, *J. Polym. Sci.*, 1960, **43**, 13–21. British Rubber Producers' Research Association, Welwyn Garden City, Herts. A new treatment of the elasticity of imperfect molecular networks has resolved the discrepancy between the results of previous theories based upon slightly different molecular models. A new relation between elastic modulus and cross-link density is derived which should be valid for all ratios of cross-links to chain ends and gives satisfactory agreement with experiment. E.H.A.

**502. Mechanical anisotropy in drawn films of regenerated cellulose.** N. WILSON, *J. Polym. Sci.*, 1960, **43**, 257–266. The British Rayon Research Association, Wythenshawe, Manchester. The Young's moduli of films of regenerated cellulose, drawn before and after saponification respectively, have been measured both along and perpendicular to the direction of drawing. For both kinds of film the longitudinal modulus increased markedly with draw ratio whilst the transverse modulus decreased slightly. At high draw ratios the moduli differed by a factor of 5 at 65% relative humidity and a factor of 10 at 100%. E.H.A.

**503. Polyethylene specific volume, crystallinity and glass transition.** P. R. SWAN, *J. Polym. Sci.*, 1960, **42**, 525. Union Carbide Co., Bound Brook, New Jersey, U.S.A. Extrapolation of melt specific volume to give that of the amorphous phase in solid polyethylene is shown to be invalid for the material studied. A new approach to the calculation of percent crystallinity is proposed which uses only the total and crystalline specific volumes and their temperature dependence. The results indicate a lower specific volume in the amorphous phase than is given by extrapolation of melt data and this is attributed to the constraint exerted by the crystalline phase. A small change of slope in the total specific volume vs. temperature curve was found at the glass transition temperature. E.H.A.

**504. Diisocyanate-linked polymers.—II. Mechanical and swelling properties of some polyurethane elastomers.** T. L. SMITH and A. B. MAGNUSSON, *J. Polym. Sci.*, 1960, **42**, 391. Jet Propulsion Laboratory, California, Institute of Technology, Pasadena, California, U.S.A. The glass transition temperatures in a series of polyurethane elastomers increased linearly with the concentration of urethane groups "$U$". At a given value of "$U$" and constant $(T—T_g^1)$ the extensibility of the polymer was inversely proportional to the number of chains per unit volume but the tensile strength remained constant. The ultimate properties of materials at constant $(T—T_g^1)$ depended strongly upon "$U$" as did the polymer solvent interaction parameter. E.H.A.

**505. Transitions in ethylene polymers.** L. E. NIELSEN, *J. Polym. Sci.*, 1960, **42**, 357. Plastics Research Laboratory, Monsanto Chemical Co., Springfield, Massachussetts, U.S.A. A study of polyethylenes and ethylene-vinyl acetate copolymers by dynamic mechanical measurements shows the $\alpha$-transition to arise from the melting of crystallites containing

ethylene sequences of near-average length, and to depend upon the crystallite length. The $\beta$-transition is not necessarily due to branching of the polymer chains and degenerates into the $\gamma$-transition if crystallinity is destroyed. E.H.A.

**506. Dynamic mechanical and creep properties of a 23% cellulose nitrate solution ; Andrade creep in polymeric systems.** D. J. PLAZEK, *J. Colloid Sci.*, 1960, **15**, 50–75. Department of Chemistry, University of Wisconsin, Madison, Wisconsin. The properties of a solution of cellulose nitrate ($M^n \sim 94{,}000$) in diethyl phthalate showed that the creep compliance could be described by a modified Andrade expression. The double transducer of Fitzgerald and Ferry was used for measurements of dynamic shear moduli from 10 to 2800 c/s at −470 to 35°C. Some measurements were also obtained between −25° and 35°C in the range 0·06 to 11 c/s with a freely damped torsion pendulum. Creep data between −33 and 25°C were obtained by modifying the apparatus. R.B.B.

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**507. The surface chemistry of wheat gluten.—I. Surface pressure measurements.** N. W. TSCHOEGL and A. E. ALEXANDER, *J. Colloid Sci.*, 1960, **15**, 155–167. Bread Research Institute of Australia, North Sydney, New South Wales. Surface pressure measurements were carried out on gluten films spread from a dispersion in a 0·1M solution of HCl in anhydrous chloroethanol on to various substrates. It is concluded that the unusually strong cohesion shown by the films is due in part to hydrogen bonding between glutamine side chains. R.B.B.

**508. The surface chemistry of wheat gluten.—II. Measurements of surface viscoelasticity.** N. W. TSCHOEGL and A. E. ALEXANDER, *J. Colloid Sci.*, 1960, **15**, 168–182. Bread Research Institute of Australia, North Sydney, New South Wales. Measurements of the viscoelastic properties of gluten have been carried out using an oscillating needle surface torsion pendulum having a period in air of 14 sec. The dependence of these properties on the pH and ionic strength of the substrate has been examined. Some measurements were also carried out on substrates known to break hydrogen bonds. R.B.B.

**509. Relation between maximum relaxation time and chain length.** A. V. TOBOLSKY and K. MURAKAMI, *J. Colloid Sci.*, 1960, **15**, 282–283. Frick Chemical Laboratory, Princeton University, Princeton, New Jersey. Values of the maximum relaxation time, $T_m$, for fifteen samples of polystyrene, heterogenicity index 1·5, have been obtained to give an empirical relationship between the glass temperature $T_g$, the weight average number of links in the polymer and $T_m$. Literature data for polyvinylacetate and polyisobutylene has also been evaluated. A similar relation between $T_m$, $T_g$ and $r_0^2$, the mean square end-to-end distance for a polymer in a theta solvent is also given for the same polymers.

R.B.B.

## Section E

## PASTES AND SUSPENSIONS

**510. The structural-mechanical properties of bitumens from different oxidation processes.** A. I. IVANOV and N. V. MIKHAÏLOV, *Kolloidnyi Zh.*, 1960, **22**, 176. Building Research Inst., Moscow. Emulsion-cavitation oxidation is found rheologically superior to batch-stills and emulsion methods, using an electronic elasto-viscometer. The first shows greatest falls in viscosity in breakdown, higher relaxation times and shear moduli than those prepared by the other methods. [Russian, English abstract] G.W.S.B.

**511. The Influence of low temperatures on bituminous water-proofing materials.** J. RATAJ, *Archiwum Inzynierii Ladowe*, 1960, **6**, 237–266. Theoretical and experimental researches on the nature of the damage arising from moisture and repeated freezing of cardboard waterproofed with bituminous mixes of the type used for roofing are reported. [Polish] P.F.

**512. The rheology of asphalt. II. Flow characteristics of asphalt.** F. H. GASKINS, J. G. BRODNYAN, W. PHILIPPOFF and E. THELEN, *Trans. Soc. Rheol.*, 1960, **4**, 265–278. The Franklin Institute Laboratories for Research and Development, Philadelphia, Pennsylvania. The rheological properties of ten representative asphalts were investigated under conditions of steady-state shear and laminar flow. Two instruments were utilized : a coni-cylindrical (rotational) viscometer and a high-pressure capillary tube viscometer. The results of the investigation show that asphalts are visco-elastic bodies which exhibit both Newtonian and non-Newtonian flow behavior with no evidence of yield value, structural breakdown or work-hardening. Thus asphalts, deliberately selected to represent extremes in structures and properties, are similar to concentrated polymer solutions and molten polymers in their response to stress. The extreme variations noted in the rheological behaviors of asphalts can generally be accounted for by the parameters—time, temperature, and stress. Author

**513. The rheology of asphalt. III. Dynamic mechanical properties of asphalt.** J. G. BRODNYAN, F. H. GASKINS, W. PHILIPPOFF and E. THELEN, *Trans. Soc. Rheol.*, 1960, **4**, 279–296. Franklin Institute, Laboratories for Research and Development, Philadelphia, Pennsylvania. The dynamic mechanical properties of ten asphalts, representing three major categories, have been determined using a variety of instruments. The validity of the time-temperature superposition principle was established by the agreement between data obtained at high frequencies and values predicted by superposition of low frequency, low temperature, measurements. This made it possible to describe the properties of asphalts by three general curves : the dependence of $G'$ and $\eta'$ on the reduced frequency and the temperature dependence of $a_T$. These curves have been determined experimentally. The curves of the moduli versus

reduced frequency cover approximately twenty-three decades of reduced frequency at 25°C. The temperature dependence was seen to be that given by the Williams-Landel-Ferry equation over a wide range of temperature. The characteristic temperature, $T_s$, was found to be nearly equal to the Ring and Ball softening points of the asphalts. Other bitumens, such as coal tar and a filled asphalt, have the same general characteristics. A rearrangement of Rouse's theoretical equations as modified by Ferry made it possible to estimate the molecular weights of the flow units and these were seen to be quite large. Author

**514. Shearing characteristics of dense sands at different rates of strain.** S. PRAKASH and S. VENKATESAN, *J. Sci. Industr. Res.*, 1960, **19A**, 219–223. University of Roorkee, Roorkee, India. Two cohesionless natural sands were tested in a dry and dense state in a direct-shear apparatus at rates of strain between 0·24 and 1·93 per cent per minute and at normal stresses of 0 to 75 p.s.i. The results show that (i) the angle of internal friction of the sands is not affected by the rate of strain : (ii) the secant modulus of deformation at failure increases with applied normal stress ; (iii) the tangent modulus of deformation at 40 per cent strength increases with the applied normal stress and with the rate of strain ; and (iv) it is possible to compute the ultimate shearing strength from the peak shearing strength and the rate of expansion at failure. Author

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**515. Experimental investigations on the rheological properties of finely dispersed mineral suspensions.** U. TS. ANDRES, *Kolloidnyi Zh.*, 1960, **22**, 137. Institute of Hot Minerals, Acad. Sci., Moscow. Investigates relationship between degree of dispersion and ratio of plastic viscosity to yield-value using coaxial cylinder viscometer. [Russian, English abstract] G.W.S.B.

**516. Studies on the formation of helical deoxycholate complexes.** D. M. BLOW and ALEXANDER RICH, *J. Amer. Chem. Soc.*, 1960, **82**, 3566–3571. The Biology Department, Massachusetts Institute of Technology, Cambridge, Massachusetts. Viscometric studies of the conditions favouring the formation of complexes and for observing thixotropic behaviour. The mechanism of the thixotropic behaviour in relation to the molecular structure is discussed. W.H.B.

**517. Flow properties of paints.** ANON., *Paint Manuf.*, 1960, **30**, 308. Report of a Symposium held in Cleveland, Ohio, September 1959. Among the more fundamental problems still awaiting a complete solution is that of defining the coefficients of flow equations which are independent of the instrument with which measurements are made. Although in some cases, precise measurement of viscosity coefficients can be correlated with paint properties (levelling, ease of brushing, etc.), these latter are very sensitive to small differences in the former ; small errors can completely confuse any correlation. Development is restricted by underdeveloped theory of flow and inadequate development of accurate and theoretically significant instruments. R.J.C.

**518. Elastic and strength properties of plastic disperse systems with reference to thixotropy.** V. P. PAVLOV and G. V. VINOGRADOV, *C.R. Acad. Sci. USSR*, 1958, **122**, 646–649. [Russian]

**519. Binding of surfactants by polymers.** S. SAITO, *J. Colloid Sci.*, 1960, **15**, 283–286. Research Laboratory of Momotani-Juntenkan Ltd., Ichioka 5, Minatoku, Osaka, Japan. Some ionic surfactants are bound in water by various nonionic polymers forming water-soluble adsorption complexes. Viscosity measurements have been used to investigate the mechanism of binding in polyvinylpyrrolidone solutions with added sodium dodecyl sulphate or sodium dodecyl polyonyethylene sulphates of varying composition. R.B.B.

## Section F

## LIQUIDS

**520. The rheological properties of glycerine solutions.** I. A. DUMANSKII and L. V. KHAÏLENKO, *Kolloidnyt Zh.*, 1960, **22**, 277. Inst. of General and Inorganic Chem., Nat. Acad Sci., Kiev. Small but definite deviations from Newtonian behaviour in glycerine-water mixtures are ascribed a pseudo-polymer structure formed by hydrogen bonding. [Russian, English abstract] G.W.S.B.

**521. Effect of sudden water release on the reservoir free outflow hydrograph.** V. M. YEVDJEVICH, *J. Res. Nat. Bur. Stand.*, 1959, **63B**, 117–130.

**522. Viscosity of concentrated urea-lithium bromide solutions.** I. I. GESCHWIND, *Nature, Lond.*, 1960, **187**, 324–325. Chemical Dept., Carlsberg Laboratory, Copenhagen, Denmark. The results indicate that when both urea (8*M*) and lithium bromide (7*M*) are present in high concentrations in a solution marked interactions occur. It has been suggested that this is due to complexes with the formula $LiBr.nCO(NH_2)_2$, or to the formation of chain-like molecules which collect together to form fibrils (these latter being destroyed by dilute acetic acid). However, addition of acetic acid to the lithium bromide-urea solution reduced the flow time to that recorded when the solution was diluted with water. Thus if long fibrils do form in 8*M* urea solutions their stability may be enhanced in the presence of concentrated lithium bromide by a mechanism similar to that proposed for the stabilisation by lithium bromide of hydrogen-bonding in proteins. W.G.C.

**523. The coalescence of liquid drops with flat liquid/liquid interfaces.** G. E. CHARLES and S. G. MASON, *J. Colloid Sci.*, 1960, **15**, 236–267. Department of Chemistry, McGill University, Montreal, Canada. The influence of temperature, drop size, diffusion, interfacial contamination and of an electrostatic field on the drop stability were investigated. Distilled water was used as one liquid, benzene, carbon tetrachloride and heptane were employed as the other liquid. The deformation of the drop near to the interface is considered. R.B.B.

## Section G

## GENERAL

**524. Rheology and dental materials.** R. H. ROYDHOUSE, *Trans. Soc. Rheol.*, 1960, **4**, 131–140. Northwestern University Dental School, Chicago, Illinois. A brief review of dental techniques and materials suggests the usefulness of rheology in testing and understanding the behavior of these materials. Little has been investigated or reported upon in this application, and a set of criteria for dental materials is given ; these are the yield value, the apparent viscosity, flow-load changes, thixotropy, and the rate of change of consistency ; the first is most important. Parallel plate plastometry is chosen as a system for testing because of its simplicity of operation and aptness as a model of the dental techniques. Some general conclusions related to this machine and its application are given, but the paper is of a descriptive nature. Author.

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**525. Rheology as an aid to the specification of cheese types.** G. W. SCOTT BLAIR, *Dairy Ind.*, 1960, **25**, 585. National Institute for Research in Dairying, Univ. of Reading, England. Quality standards for body of different types of cheese might be established on a rheological basis. Three principal methods are considered : (1) dash-pot spring models, (2) principle of intermediacy and (3) development of *ad hoc* tests tesembling processes of handling and manufacture followed by some type of multivariate analysis. Definite rheological specifications might be accepted for the principal cheese types. G.W.S.B.

**526. The Marangoni effects.** L. E. SCRIVEN and C. V. STERNLING, *Nature, Lond.*, 1960, **187**, 186–188. Chem. Engineering Dept., Shell Development Co., Emeryville, California. A review of the Marangoni effects, i.e. the motion in a fluid interface, and the departure from equilibrium interfacial tension that is produced by extension or contraction of an interface. W.G.C.

**527. Initiation of chemical reactions by mechanical forces.** R. SCHNURMANN and I. S. STRINGER, *Nature, Lond.*, 1960, **187**, 587–588. Esso Research Ltd., Abingdon, Berks. The viscosities of lubricating oils, sheared in an internal combustion engine, were found to decrease with the time of running, while the temperature coefficients of viscosity increased. If the engine was driven by leaded fuel these changes became more marked. Where an oil contained a proportion of poly*iso*butene, the viscosity loss for a given shearing stress was dependent on the concentration and molecular weight of the polymer. W.G.C.

**528. The effect of viscosity on the quantum yield for iodine dissociation.** D. BOOTH and R. M. NOYES, *J. Amer. Chem. Soc.*, 1960, **82**, 1868–1872. Chandler Laboratory, Columbia University. Quantum yields for dissociation of iodine by the 4358 Å Hg line at 25°C for solutions in hydrocarbons over a $10^3$ viscosity range. W.H.B.

**529. Low-pressure gas flow in consolidated porous media.** R. Ash and D. M. Grove, *Trans. Faraday Soc.*, 1960, **56**, 1357–1371. Queen Mary College, Mile End Road, London, E.1. A study of the flow of the inert gases, $H_2$, $N_2$, $O_2$, Ethane, $CO_2$ and $SO_2$ through a cylindrical rod of porcelain ceramic. Viscous slip was observed at the highest pressure (30 cm. Hg) but below 2 cm. Hg, molecular streaming set in. W.H.B.

**530. Apparatus for the measurement of gas velocity in furnaces and models.** A. E. Pengelly, *J. Sci. Instrum.*, 1960, **37**, 339–346. The United Steel Companies Ltd., Moorgate, Rotherham, Yorks. A range of Pitot tubes is described together with an electromagnetic transducer micromanometer. The assembly is designed for measurement ol gas velocity over a large range of temperatures. Author

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**531. The significance of rheology in the making and using of paper.** A. H. Nissan, H. G. Higgins and A. Lagani, Jr., *Trans. Soc. Rheol.*, 1960, **4**, 207–232. Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York. A brief review of paper making indicates that rheology is an important factor at many points. The most significant are (1) rheology of fiber suspensions, (2) rheology of wet webs of fibers with 1 : 4 to 1 : 2 solid to water ratios, and (3) rheology of air-dry paper in use. The first two subjects are briefly reviewed. Attempts to represent paper behavior in terms of mechanical models of springs and dashpots are summarized and reasons for their rejection advanced. Instead, support is given to interpretations based on molecular and thermodynamic parameters as a basis for a theory of the rheological behavior of hydrogen-bonded solids. Predictions of the theory appear to be confirmed not only by paper but also by ice, cellulose sheets, nylon and other hydrogen-bonded materials. Attempts are made to explain by means of this theory the influence of water, chemical modification of the fibers, and other factors on the rheological constants of paper, and to account for its time-dependent behavior. The essential contribution of the theory is that it relates the variations in behavior to an important parameter, $n$, the number of hydrogen-bonds per unit volume of material. Thus, changes in rheological behavior reflect changes in $n$ ; these changes can be treated by methods of chemical kinetics. Author

**532. Stress-optical properties of silicones.** W. Philippoff, *Trans. Soc. Rheol.*, 1960, **4**, 169–177. The Franklin Institute, Philadelphia, Pennsylvania. The stress-optical properties of silicone solutions have been reported in previous papers. However, the extensive description of the experiments including a check of the angle $\chi$ measured in flow birefringences with the one determined by the Weissenberg Rheogonimeter have not yet been given. This has now been done and is given in this paper. Furthermore, the stress-optical properties of silicone rubber, a transparent polymer crosslinked by atomic radiation, was investigated. The stress-optical coefficients $C$ of the silicone solutions in toluene and of the cross-linked rubbers are very similar. Author

**533. The theory of the operation of continuous thickeners.** W. S. Wise, *Ind. Chemist*, 1960, **36**, 77. Department of Sugar Research, Imperial College of Tropical Agriculture, Trinidad.

**Non-Newtonian Fluids : Fluid Mechanics, Mixing, and Heat Transfer.** By W. L. WILKINSON, Pergamon Press, 1960. XIV + 138 pp. 37s. 6d.

THE stated aim of this book is to present the results of various specialists in the field of rheology in a form which the engineer can readily understand and apply to problems he is likely to encounter in the field of non-Newtonian technology. Accordingly, about half the text is devoted to a lucid account of the simpler fundamental concepts of rheology : viscosity and non-Newtonian behaviour, thixotropy and rheopexy, dilatancy, linear viscoelasticity. The principles underlying the use of rotational and capillary viscometers are given and it is shown how data from the latter may be analysed to give the flow curve. Certain commercial rotational instruments, including the Roberts-Weissenberg rheogoniometer, are described.

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The engineering topics dealt with arise mainly from work published during the past ten years. The most detailed treatment concerns the important problem of pressure drop and heat transfer in the flow of incompressible, inelastic, non-linear liquids through pipes of circular cross-section ; both laminar and turbulent flow are treated, the former somewhat more extensively than the latter. It appears that, for certain non-Newtonian liquids at least, the engineer's conventional charts can be adapted and used for the solution of practical design problems : provided that the shear stress (in laminar flow) depends on shear rate alone, a modified Reynold's number can be defined whose measured values, when plotted against measured values of the friction factor (a measure of pressure drop per unit length) fall on (or nearly on) a single curve for a variety of systems ranging from clay suspensions to polymer solutions. Other topics, treated in rather less detail, include flow through an annulus, screw extruders, rolling and mixing processes.

On the whole, the author makes clear the limitations of the treatment (e.g. that the neglect of elastic effects will often be a serious limitation in cases of turbulent flow and flow through valves and non-uniform pipes) although he might perhaps have said a little more on this point (e.g. that the elementary mathematical theories described in chapter 1 are not capable of accounting for the Weissenberg effects outlined on pp. 48, 49). There are only a few misprints (e.g. on p. 1, a sign of proportion is printed as an alpha ; on p. 100, there is a change from a lower case s to a capital S), and one redundancy : " strictly rigorous ", p. 65. This book fulfils a real need at the present time and should prove useful not only to engineers but to others who want a clear, unvarnished introduction to elementary rheology.

A. S. LODGE

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